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ABSTRACT

This briefing book outlines program activities and contains a set of briefing papers which provide a background for the conference. The conference agenda is in the first section, followed by two sections previewing each of the issues and theme conference sessions, including an overview of each topic, specific issues involved, the conference presentation, and presenters. The fourth section outlines the 47 workshops offered at the conference, and section five describes 44 conference exhibits. The final section contains five briefing papers: "What Are the Challenges to 'Scaling Up' Reform?" (Stephen P. Klein; and others); "Workforce Issues in Spreading Excellence in Science and Mathematics" (Ray Marshall); "Tech Prep: A Business Perspective" (Carver C. Gayton); "Full-scale Implementation: The Interactive 'Whole Story'" (Susan B. Millar); and "Simulation and Modeling in Precollege Science Education" (Wallace Feurzeig). (MAS)

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NATIONAL SCIENCE FOUNDATION

UNITED STATES DEPARTMENT OF EDUCATION

January 1995

Dear Education Leader:

We are pleased that you have accepted our invitation to attend the NSF/ED conference, *Joining Forces: Spreading Successful Strategies*. We look forward to your participation. It is our hope that you will return home with new insights and new energy to move the reform agenda ahead.

This briefing book previews conference activities so that you may choose those sessions you wish to attend. The book also contains a set of briefing papers that provide you with background for conference activities. Reading these papers in advance of the conference will assist your active participation in the sessions. There are papers on scaleup, workforce issues, business involvement, implementation, and technology.

In accepting our invitation, you have committed yourself to contribute to the conference activities; to plan the next steps toward educational excellence; and to undertake new activities over the next three-month, six-month, and one-year periods.

We offer the following questions for your consideration prior to the conference, and ask that you keep them in mind as you attend conference sessions:

(1) What concrete strategy of your work could be used to "scale up" its effectiveness and to move beyond its current activity range?

(2) Is the overall activity — particularly the strategy being employed to scale up its effectiveness — something that has been, could be, or should be broadly used by others? What strengths give your strategy a wide range of uses? What are its limitations?

(3) How does your work fit in with the systemic reform of education in your school district, city, state, or region? Is it linked with area systemic initiatives? Is it tied into the education structure (the bureaucratic structure) in such a manner that it will continue to be effective?

(4) Does the success of the activity depend on unusual partnerships (for instance, partnerships that are outside a conventional structure with clear reporting lines)? Can the partnerships be maintained?

(5) Is the activity a success? Can its success be documented? Is the documentation such that others (e.g., students, parents, school boards, state-level boards or committees, and the general public) can readily recognize its success? What evaluation methods are most effective and how can they be used in other settings?

Please remember to bring this briefing book to the conference. We look forward to your participation, and thank you for your commitment and all that you contribute to education reform.

Sincerely,

Luther S. Williams
Luther S. Williams
Assistant Director, Education
and Human Resources
National Science Foundation

Thomas W. Payzant
Thomas W. Payzant
Assistant Secretary, Elementary
and Secondary Education
U.S. Department of Education

Sharon P. Robinson
Sharon P. Robinson
Assistant Secretary, Educational
Research and Improvement
U.S. Department of Education

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AGENDA

NATIONAL SCIENCE FOUNDATION/U.S. DEPARTMENT OF EDUCATION
INVITATIONAL CONFERENCE ON SYSTEMIC REFORM

Joining Forces: Spreading Successful Strategies

February 23–25, 1995
Renaissance Hotel
999 Ninth Street, N.W.
Washington, D.C.

Thursday, February 23

4:00 p.m. to 6:00 p.m. Registration and Check-in

6:00 p.m. to 7:30 p.m. Buffet and Exhibits

7:30 p.m. to 8:00 p.m. Opening Program

> Welcome Remarks by: **Luther S. Williams**, Assistant Director for Education and Human Resources, National Science Foundation; **Thomas W. Payzant**, Assistant Secretary for Elementary and Secondary Education, U.S. Department of Education; and **Sharon P. Robinson**, Assistant Secretary for Educational Research and Improvement, U.S. Department of Education

8:00 p.m. to 10:00 p.m. 44 Exhibits

Friday, February 24

8:00 a.m. to 8:45 a.m. Continental Breakfast
8:45 a.m. to 9:00 a.m. Conference Introduction and Logistics
9:00 a.m. to 10:00 a.m. Keynote Address by **M.R.C. Greenwood**, Associate Director for Science, White House Office of Science and Technology Policy

10:00 a.m. to 10:15 a.m. Break

10:15 a.m. to 12:15 p.m. Group Sessions: Focus on Successful Expansion Strategies

> Successful strategies used in NSF and the Department of Education efforts to spread them beyond their initial origins will be presented. There will be 18 two-hour interactive sessions with brief (less than half the allotted time) presentations, followed by discussion and exchange of ideas. Session participants will add their expertise.

SEE BRIEFING BOOK FOR LISTINGS AND DESCRIPTIONS

12:15 p.m. to 1:45 p.m.	Luncheon Plenary Session, Address by **Madeleine Kunin**, Deputy Secretary, U.S. Department of Education
2:00 p.m. to 8:00 p.m.	44 Exhibits
2:00 p.m. to 6:30 p.m.	Theme Sessions/Workshops/Exhibits The afternoon activities will run in three time periods: 2:00 to 3:20 p.m. 3:35 to 4:55 p.m. 5:10 to 6:30 p.m. There will be three interactive "theme sessions" focusing on issues from the morning group sessions, 47 workshops, and the 44 exhibits open until 8:00 p.m. SEE BRIEFING BOOK FOR TIMES, LISTINGS, AND DESCRIPTIONS
6:30 p.m. to 8:00 p.m.	Reception/Cash Bar (exhibits continue throughout)

Saturday, February 25

8:00 a.m. to 8:30 a.m.	Continental Breakfast
8:30 a.m. to 10:00 a.m.	Plenary Session: Panel on *Designing Your Next Steps* **Luther S. Williams, Thomas W. Payzant, and Sharon P. Robinson**
10:00 a.m. to 10:30 a.m.	Break
10:30 a.m. to 12:15 p.m.	Birds-of-a-Feather Discussions To Design Next Steps
12:30 p.m. to 2:00 p.m.	Luncheon and Conference Summary Panel *Designs for Your Next Steps* Discussion with Audience

Editors Note: This document uses "scaleup" as a noun, "scale up" as a verb, and "scale-up" as an adjective, as recommended in Webster's Ninth New Collegiate Dictionary (1988) *and the* United States Government Printing Office Style Manual (1984).

ISSUE SESSIONS

Group 1: Calculus Reform—Taking It to the Limit

Scaling up a reformed calculus instruction program from only a few sections to every classroom poses formidable challenges. Nevertheless, scaleup for the first year of calculus is now occurring at several of the nation's colleges and universities. Beginning with a few sections taught by volunteer faculty, institutions are reforming the teaching of calculus in all sections. Also, senior faculty who had not previously taught calculus are now teaching this critical course of the undergraduate curriculum.

This effort has required a significant reallocation of institutional resources and faculty time. Three essential features of the improved teaching of calculus at the University of Arizona are (1) adoption of the reformed calculus text developed through an NSF grant by a consortium led by Harvard University; (2) introduction of alternative instructional practices; and (3) integration of technology into the learning of calculus.

The Arizona experience provides an excellent model to analyze the issues, barriers, and benefits that occur through a scaleup effort of this magnitude.

Issues:

- Articulation of the desired goals and objectives of the reform
- Identification of mechanisms to provide the necessary faculty development
- Development of one's own materials or adoption/adaptation of materials developed elsewhere
- Identification and implementation of appropriate technology
- Strategy to obtain necessary institutional resources
- Role of the department and institutional leadership and administration
- Response to, and anticipation of, negative reactions and setbacks

Presentation: Individuals involved in the Arizona effort will lead the discussion on what has been learned—what has worked and what has not—in achieving full implementation.

Presenters: Elizabeth Teles, NSF, Division of Undergraduate Education (Moderator)
Representatives from the University of Arizona faculty and administration

Group 2: Institutional Change in Teacher Preparation Programs, Scaling Up and Scaling Out: A Comprehensive Approach

The expansion of excellence in teacher preparation from a single department's initiative, throughout an entire institution and, ultimately, to actions statewide is the focus of this session. Pathways to comprehensive systemic programs, such as the NSF Collaboratives for Excellence in Teacher Preparation, include scaling up of smaller, focused programs in teacher preparation to institution-wide commitment that fully engages the cooperation of science, mathematics, and engineering faculty, and faculty in the schools and colleges of education, and also the scaling out to related institutions. A crucial and difficult step of scaleup is the expansion of support from a few key faculty and administration to an entire institution.

Issues:

- Relevance of teacher preparation reform to science education of all students
- Faculty priorities and the reward system
- Creating fruitful relationships with the K–12 sector

Presentation: The session will be initiated by remarks by Albert Yates, President of Colorado State University, one of the collaborative institutions within the Rocky Mountain Teacher Education Collaborative. The participants will then be divided into three groups, each led by representatives from the current Collaboratives, to discuss the issues listed above.

Presenters:
Terry Woodin, NSF, Division of Undergraduate Education (Moderator)
Albert Yates, Colorado State University
Representatives from the NSF Collaboratives for Excellence in Teacher Preparation with projects in:
Group 1—Maryland
Group 2—Montana
Group 3—Louisiana

Group 3: Statewide Systemic Initiatives: Diverse Approaches to Scaleup

The Statewide Systemic Initiative (SSI) program, which encourages statewide educational systemic reform in 25 states, illustrates that scaleup can occur in many different forms. This session will explore scaleup efforts in two SSI states—Maine and California—and will examine common themes that enable scaleup efforts in any state.

The Maine Mathematics and Science Alliance uses a broad-based network of partners to develop and implement strategies for change, including extensive professional development institutes for teachers and administrators and the use of a system of model schools as laboratories for the development of new curricula and teaching methods. Scaleup involves increasing the number and locations of institutes each year and expanding the model schools into regional resource centers.

Systemic reform has been well established for the past decade in California, and has produced state frameworks, a performance-based statewide assessment system, and statewide materials adoption procedures. The California strategy has focused strategically on scaling up and strengthening teacher networks in elementary science and middle school mathematics because these areas act as "gateways" that keep underrepresented students from gaining full access to rigorous mathematics and science programs. After three years, 20 percent of the state's elementary and 40 percent of the state's middle schools are participating in the SSI. In addition, a statewide Technical Implementation Committee fosters greater coordination and collaboration among existing programs throughout the state and engenders policy level reforms supportive of the California SSI vision.

Issues:

- How important is the principal investigator to the success of the initiative, and what are some characteristics of an effective leader?
- Who should be included in the management team of the initiative, and how is consensus built around vision and implementation strategies?
- What is the influence of state size on specific strategies?
- What do the two examples offer that can be adapted to other states?
- What are the challenges in aligning state policy with the vision for systemic reform?
- How does an initiative garner grass-roots support and ownership while ensuring quality and accountability?
- What are some intermediate benchmarks for successful systemic reform?

Presentation: The panel will include a brief overview of each of the two states, followed by discussion of the issues with audience participation.

Presenters:
Carolyn Mahoney, NSF, Office of Systemic Reform (Moderator)
Thomas Clark and Jackie Mitchell, Maine SSI
Bob Polkinghorn, California SSI

Group 4: Expanding Educational Excellence: Mosaic, World Wide Web, Internet, and AskERIC

The availability of easy-to-use interactive multimedia over the Internet provides a limitless opportunity to expand educational excellence. The Internet and its associated development environment, the World Wide Web (WWW), enable teachers and students to connect effortlessly with others the world over. They are able to present, retrieve, and share information electronically between computer systems. How this technology should be used to improve educational excellence is being explored by numerous programs supported by NSF and the U.S. Department of Education. It opens a vast vista for research, collaboration, and exploration from within the classroom. This panel brings together a few of the investigators in this area to demonstrate the implications and challenges facing educators in the use of the Internet.

Issues:

Effective Use of the Technology

- Why—Are we managing change and sharing information using the information superhighway?
- When—When should one apply the technology? Does it enhance or detract from the teaching process? Is this another toy or a learning tool?
- Who—Who has access to this information? Who pays what?
- What—Developing learning communities at the school, state, and national levels—is this truly our mission?
- Where—What is the WWW connection and its use?

Dissemination Considerations

- Models of excellence—NSF selected projects and AskERIC
- Product evaluation (Mosaic and AskERIC)—Where they started, where they are, and where they are going
- Making information available through technology
- Media–multimedia dimensions

Presentation: Panel presentation with question and answer period. Illustrative graphical information will be displayed in a PowerPoint presentation.

Presenters:

Art St. George (Moderator) and Jeff Graber, NSF, Division of Research, Evaluation and Dissemination
R. David Lankes, Coordinator, AskERIC Research and Development
Richard Tkachuck, ERIC Clearinghouse on Information and Dissemination

Group 5: Reaching the Nation through the MAGIC SCHOOL BUS

The MAGIC SCHOOL BUS presents science through activities that draw upon the characters and style of the popular series of science trade books by the same name, which are eagerly read by many children in the target age range, known and used by teachers, and recommended by librarians. The project consists of a national television series, two copies of a 1,200-square-foot traveling exhibit, a museum activity/program trunk used by youth museums and science centers nationwide to engage young visitors in hands-on science activities, an activity and programming guide used by leaders of youth groups, and teachers guides for use in elementary classrooms. The project also disseminates activities through eight national youth groups to encourage multicultural participation in science programs. These organizations are the AAAS Black Churches Project, Aspira Inc., the Boys and Girls Clubs of America, 4-H, Girl Scouts, Girls Incorporated, the National Urban League, and YouthALIVE!.

The following efforts contributed to the scaleup of this project.

- The MAGIC SCHOOL BUS television series was aired on 302 PBS stations, reaching 96 percent of the country.
- Over 70 museums used the museum activity/program trunk to conduct hands-on science activities for youth.
- 285,000 copies of the activity guide were made available to elementary school science teachers nationwide. Another 138,000 copies were used by community and youth groups. Three national Hispanic organizations used 6,300 guides.
- The traveling exhibit visited 16 children's museums across the country.
- The eight national youth organizations distributed 57,600 activity guides to local chapters and supported hands-on science activities through their chapters.

Issues:

- Opportunities and challenges experienced by a national publisher, television producers, museum and community educators, formal educators, and exhibit designers in developing the project
- Successful and unsuccessful practices and aspects of the project

Presentation: Examples of the final products will be demonstrated and shared with those attending the session. The audience also will be asked for suggestions about how such an endeavor might be made even more effective and encouraged to propose new types of collaborations that might be effective in the enhancement, dissemination, and adoption of other outstanding science and mathematics endeavors.

Presenters:

Cheryl Gotthelf, Scholastic Productions
Beverly Sanford, Discovery Place, Inc.
Michael Templeton, Consultant, Portland, Oregon

Group 6: How Do We Know How To Scale Up Exemplary Projects?

We will look at lessons to be learned from the implementation of the Interactive Mathematics Project (IMP) at two large urban school systems, Boston and Philadelphia. These cities implemented the IMP curriculum in the fall of 1992 and began instruction in a number of high schools in September 1993. Both programs survived their first full year of classroom implementation and were considered successful. Both cities are expanding the number of schools in which ninth-grade IMP is implemented and are continuing with 10th-grade IMP in the initial set of schools.

During the 1994–95 school year, IMP will be used in 99 schools in 12 states. Each of these schools has made a three- or four-year commitment to IMP, ensuring participation of heterogeneous student populations and parent education about the new program. These communities have committed substantial financial resources to fund special teacher training, equipment purchases, and additional preparation periods for teachers. The original pilot and field testing of IMP materials took place in three San Francisco area schools: Mission High School, an inner city high school; Berkeley High School, an urban school with a wide range of student abilities and economic backgrounds; and Tracy Joint Union High School, a semirural high school. At Berkeley and Mission High Schools, 40 percent of the students placed in first-year IMP had been slated for remedial courses.

Issues:

- What are the costs of implementing standards-based curriculum materials?
- How will we reach the multitude of teachers with an adequate amount of enhancement, not just in terms of cost, but of the capacity of the system to deliver quality enhancement?

Presentation: This session will be guided by project directors from the parent IMP and each of the cities. A brief presentation on the experiences in each city will be given, and the audience will then try to come up with the attributes needed for implementation and the various road blocks that are often present. The whole group will generate a set of lessons learned and describe their applicability to the implementation of other new curricula.

Presenters:
Carla Oblas, Northeastern University
Diane Resek, Interactive Mathematics Project
Ned Wolff, Beaver College

Group 7: New Paradigms for Graduate Education

Stimulating significant systemic change and scaleup in graduate education involves defining new paradigms for the advanced training of future generations of scientists and engineers capable of addressing complex situations in an increasingly global arena. The Graduate Research Traineeship (GRT) program provides support for predoctoral student positions in critical and emerging areas of science, mathematics, and engineering and complements major systemic reform strategies currently targeted at K–12 and undergraduate levels by (1) catalyzing the development of innovative approaches to graduate education in response to changing national priorities; and (2) developing a graduate student support base among all underrepresented groups and across all geographical sectors.

The GRT Program promotes (1) expanded flexibility in advanced training of scientists and engineers; (2) accelerated efforts to build effective partnerships; (3) intellectual integration among diverse disciplines; and (4) enhanced international collaborations. In addition, GRT has tremendous potential for improving knowledge transfer between academia, industry, and other potential users of scientific knowledge.

A GRT award to the University of Delaware, for example, supports five graduate traineeship positions in computer science with an emphasis on the development of an intelligent natural language communication system. The graduate program involves (1) cross-disciplinary study among computer science, linguistics, and psychology; (2) industrial internships to introduce students to technology transfer; (3) international research opportunities that will expose trainees to international researchers and technology being developed through European Esprit projects; (4) classroom teaching experience to prepare trainees for educating future teachers; (5) cost-sharing by the University of Delaware and industrial organizations; and (6) aggressive recruitment and retention efforts to increase student diversity in the training program.

Issues:

- The effective integration of research and education
- Effective strategies for establishing graduate education coalitions (e.g., interinstitutional, United States–international, and industry–university)
- The ability to provide a diverse human resource base for scientific leadership in areas of national priority

Presentation: Presentation by GRT project directors and NSF staff will serve as the basis for a discussion of successful graduate level strategies that will produce the next generation of research-trained scientists and engineers. These professionals must be prepared to assume leadership positions in academia, the private sector, and government.

Presenters: To be announced

Group 8: Reform of Elementary School Science: Model-Based Implementation

Working in partnership for the past eight years, the Caltech Precollege Science Initiative and the Pasadena (CA) Unified School District have developed an innovative elementary science program which is the model for this scaling-up effort. When the partnership began, there was very little science in elementary school classrooms in Pasadena, and what was present was textbook based. Today, hands-on, inquiry-based science is present in all elementary schools, and students are engaged in identifying questions, working on problems in groups, collecting and analyzing data, drawing conclusions, and communicating their findings. As a result of this success, NSF has funded the Caltech/Pasadena partnership to support other urban school districts in California that wish to introduce or enhance high-quality hands-on science instruction based on the Pasadena model.

The main features of the Pasadena model include (1) initial creation of a fully transformed pilot school; (2) exemplary classroom instructional materials; (3) ongoing professional development for administrators and teachers; and (4) frequent mentoring by a district resource teacher. Moreover, critical to the entire change effort is the partnership of the school district with practicing scientists and engineers from a university, college, industry, or the community.

Issues:

- What has been learned about systemic reform of elementary school science that appears to be essential for all projects?
- What role does an outside organization play in local systemic reform, and how critical is this role?
- What can be done to help keep a school system focused on one type of reform long enough to support the desired change?
- What should be expected from each of the collaborators in efforts such as this to ensure long-term success of the scaling-up effort?
- What type of evidence can be gathered to document that positive change is taking place within school systems, schools, and classrooms?

Presentation: The session will present an abbreviated workshop of the type that would be presented for interested and eligible school districts. This will include detailed information about the model for districtwide change, an explanation of how the Pasadena/Caltech partnership will provide the types of resource needed for replication, and a discussion of the commitment expected from new partnerships.

Presenters: Jim Bower, California Institute of Technology
Jennifer Yure, Pasadena District Service Center

Group 9: Technological Implementation and Maintenance in Diverse Settings: Blue Skies, National Geographic (NG) Kidsnet, and Common Knowledge: Pittsburgh

Blue Skies, NG Kidsnet, and Common Knowledge: Pittsburgh have grown as a direct result of multimedia and electronic networks. The projects presented will show how project-based hands-on science activities at the K–12 level can be implemented and maintained in school districts of diverse types with the help of modern technology.

- Through Blue Skies, Michigan secondary schools have applied computer technology to science teaching and learning.
- NG Kidsnet, a telecomputing-based project published by the National Geographic Society, is a self-sustaining elementary school curriculum project in use by many schools worldwide.
- Common Knowledge: Pittsburgh explores the use of networking technology to reform science and mathematics education in an urban setting.

Issues:

- Institutionalizing change
- Role of technology in enabling hands-on science activities
- Teacher support and ownership of change. What makes curriculum materials widely adoptable?

Presentation: Each of the project directors will present a multimedia synopsis of their project. A question-and-answer period will follow, and hands-on learning time will be allotted for all participants.

Presenters:
Nora Sabelli, NSF, Division of Research, Evaluation and Dissemination (Moderator)
Perry Samson, University of Michigan
Bob Tinker and Alan Feldman, Technical Education Research Center
Richard Wertheimer and Mario Zinga, Pittsburgh Public School District

Group 10: Statewide Systemic Initiatives: Diverse Approaches to Scaleup

The Statewide Systemic Initiative (SSI) program, which encourages statewide educational systemic reform in 25 states, illustrates that scaleup can occur in many different forms. This session will explore scaleup efforts in two SSI states—Michigan and Montana—and will examine common themes that enable scaleup efforts in any state.

The Michigan SSI has deliberately developed a program that concentrates on enhancing the state's infrastructure to implement high quality mathematics and science education reform. Scaleup strategies include: (1) increasing funding for the state's Mathematics and Science Centers, which provide professional development and curriculum services to districts, to cover the entire state; (2) redesigning teacher education in all the state's institutions of higher education that prepare teachers to develop reform guidelines for both teacher preparation programs and introductory mathematics and science courses; and (3) recommending new directions to state policymakers.

Systemic Reform in Montana is targeted at restructuring the state's mathematics and science education curriculum and building the infrastructure for sustained teaching and learning. Building on mathematics curricular reform at the high school, this technology rich curricular reform effort is being scaled up to include restructuring elementary and middle grade mathematics, revising science curriculum at all levels, redesigning teacher preservice and inservice, and revising certification standards.

Issues:

- How important is the principal investigator to the success of the initiative, and what are some characteristics of an effective leader?
- Who should be included in the management team of the initiative, and how is consensus built around vision and implementation strategies?
- What is the influence of state size on specific strategies?
- What do the two examples offer that can be adapted to other states?
- What are the challenges in aligning state policy with the vision for systemic reform?
- How does an initiative garner grass-roots support and ownership while ensuring quality and accountability?
- What are some intermediate benchmarks for successful systemic reform?

Presentation: The panel will include a brief overview of each of the two states, followed by discussion of the issues with audience participation.

Presenters:
Janice Earle, NSF, Office of Systemic Reform (Moderator)
Glenn Allinger, Montana SSI
Nancy Mincemoyer and Teresa Staten, Michigan SSI

Group 11: From One to Ten to One: National Network of Eisenhower Mathematics and Science Regional Consortia

A national network of 10 regional consortia are funded by the Department of Education and housed in regional educational laboratories. The consortia are committed to systemic reform of mathematics and science education. The 10 consortia were originally funded with a focus on regional services, but have expanded to a network of national significance. This session will focus on four areas as examples of scaling up.

The first segment will focus on the latest technology used and recommended by the consortia, including their Internet servers, and the Eisenhower National Clearinghouse and its regional demonstration sites.

The topic of alternative assessment will address results in the area of integrated math and science instruction and student assessment. Consortia representatives will discuss the formation and support of networks of educators that are working to develop teaching resources and disseminate classroom strategies.

Also highlighted will be a focus on collaborative efforts to infuse equity as a critical strand of systemic reform in mathematics and science. A national equity network has been launched and participants will be provided with information on how to join and participate at no cost in this effort to galvanize and support equity reforms at the local, state, and national levels.

The consortia are providing training and technical assistance to district, state, and regional groups in the development and dissemination of curriculum frameworks. Through a collaborative effort, the consortia have assembled framework developers and implementors from 27 states and territories to work on national case studies that will document the process, identify the challenges and successes, and provide a "framework" for others attempting similar efforts.

Issues:

- What do we know about the different approaches to mathematics and science education reform and how can they be "scaled up" to national levels?
- What successes and challenges are being encountered with these various approaches?
- What support do these efforts need?

Presentation: Using video, computer, discussion, handouts, and visual displays, the presenters will illustrate the strands of commonality that thread through each of the consortia and expand to systemic mathematics and science education reform.

Presenters:

Pam Buckley, Appalachia Educational Laboratory, Eisenhower Math and Science Consortium (KY, TN, VA, WV)

Francena Cummings, South Eastern Regional Vision for Education (SERVE) Mathematics and Science Regional Consortium (AL, FL, GA, MS, NC, SC)

Eileen Ferrance, Eisenhower Regional Alliance for Mathematics and Science Education Reform(CT, MA, ME, NH, NY, PR, RI, WI, VT)

Wes Hoover, Southwest Consortium for the Improvement of Mathematics and Science Teaching (AR, LA, NM, OK, TX)

Keith Kershner, Mid-Atlantic Regional Consortium for Mathematics and Science Education (DC, DE, MD, NJ, PA)

John Kofel, Pacific Region Mathematics/Science Consortium (Commonwealth of Northern Mariana Islands, Federated States of Micronesia, Guam, Hawaii, Republic of Marshall Islands, Republic of Palau)

Robert McLaughlin, Eisenhower Regional Alliance for Mathematics and Science Education Reform

Rob Larson, Northwest Consortium for Mathematics and Science Teaching (AK, ID, MT, OR, WA)

Len Simutis, Eisenhower National Clearinghouse for Mathematics and Science Education

Art Sussman, Far West Regional Consortium for Science and Mathematics (AZ, CA, NV, UT)

John Sutton, High Plains Consortium for Mathematics and Science (CO, KS, MO, NE, ND, SD, WY)

Gil Valdez, Midwest Consortium for Mathematics and Science Education (IA, IL, IN, MI, MN, OH, WI)

Group 12: The Arkansas Crusades—Expanding a Model Across Academic Disciplines

The Arkansas Crusades offer a successful example of scaleup of an innovative educational program. The first Arkansas Crusade was the Arkansas Mathematics Crusade, a professional development series in the form of a graduate-level course for mathematics teachers designed to create successful learning environments featuring hands-on learning and the use of technology to promote higher order thinking. The course was designed by classroom teachers and university professors and includes long-term follow-up. Once designed, the course became the basis for a category of Eisenhower higher education grants—any university in the state can apply for Eisenhower funds to sponsor a Crusade course. By focusing the Eisenhower funds in this way, a consistent message is sent across the state.

The Crusade also uses a variety of funding sources that complement one another, including business and industry support, state funds, and Eisenhower local funds.

Following the model of the Mathematics Crusade, the K–4 Crusade integrating mathematics, science, and reading was developed with funds through the Arkansas governor's office with matching Eisenhower funds. Another example of expansion is the Science Crusade, a key component of the NSF-funded SSI program in Arkansas.

The mission, goals, strategies, and mechanics of the projects are similar for all three Crusades. All focus on investigations, hands-on instructional strategies, and a variety of assessments. Each is based around a collaboratively developed course that is available for any institution of higher education to utilize as a basis for its application for grant funds.

Issues:

- How can the collaboration between universities and schools be facilitated?
- What are the advantages and disadvantages of focusing competitive funds?
- To what extent has this focus had an impact on teaching across the state?
- How has the coordination of varying funding sources been accomplished?
- Could this work in other states?
- Will the effects be institutionalized?
- What problems were encountered? How were they overcome?

Presentation: There will be a brief discussion of the development of the Crusade courses and how they are related. A demonstration of instructional strategies with manipulatives, science equipment, and/or calculators from each of the Crusades will be explored, which will require audience participation. The remainder of the time will be used to answer questions concerning scaling up, policies, and local teacher, administrative, business, and financial support. Handouts will be provided.

Presenters: Tim Daniels, Suzanne Mitchell, and Judy Trowel, Arkansas Department of Higher Education

Group 13: The Wisconsin Cray Academy—Catalyst for Change

The Cray Academy is a two-week summer institute designed to help K–12 educators increase their knowledge of math, science, and technology education and learn strategies to provide more interesting and integrated learning experiences for their students. The first program was initiated in northwestern Wisconsin in 1988 by Cray Research, Inc. who funded the development while local Eisenhower funds supported the teachers' attendance.

The Cray Academy is a partnership among local school districts, intermediate agencies, universities, technical colleges, businesses and industries, and the state educational agency.

Expansion

The program coordinators have maintained and facilitated the growth of the Cray Academy in the northwest by seeking out funding from other businesses and by tapping into the Eisenhower statewide demonstration/exemplary funding. Additionally, coordinators from the Cray Academy assisted in an outreach effort. As a result, the Einstein Academy, the Southwest Academy, the John Muir Academy, and the Washburn Academy, patterned after the Cray Academy, have been established to serve other parts of the State by using both Eisenhower funding and business/industry support. With a grant from NSF, the expansion will continue in 1995 with the establishment of 10 new academies in Wisconsin and with dissemination to neighboring states.

Issues:

- What help is needed to assist each new academy in developing a consistent program?
- What is needed by site coordinators to assist with fund-raising activities?
- How can teachers be trained to be effective presenters in academies so that a systematic and coordinated-staff development program will be presented at each site?
- How can relationships between universities, technical colleges, intermediate educational agencies, and school districts be developed and maintained to ensure the continuation of these programs?
- How can turf battles be prevented?

Presentation: This session will feature a 15 minute introduction video and will then engage participants in an interactive discussion on several specific program elements. The discussion will focus specifically on

- The program's nontraditional staff development
- Difficulties and importance of collaboration
- Expansion to five sites
- Teacher perspective on value of the program
- Further expansion with NSF grant

Presenters:

Julie C. Stafford, Cray Academy
Charles O. Larson, University of Wisconsin—Eau Claire
Linda Cate-Dunahee, Cooperative Educational Services Agency # 10

Group 14: The California Science, Mathematics, and Technology Pipeline Program: From a Single District to a Statewide Program

This project began as a single district project funded through a federal initiative and has since been expanded, through state legislation, into a statewide program. The California Science, Mathematics, and Technology Pipeline Program is intended to identify, support, and assist elementary, secondary, and postsecondary students, particularly those from underrepresented groups, with the potential to become to become teachers of science, mathematics, or technology. The original Pipeline project was developed through an Eisenhower state grant received in 1989 from the California Postsecondary Education Commission. Passage of Assembly Bill 266 in 1993 established this idea as a statewide program. Currently, five additional sites throughout the state are engaged in planning Pipeline centers. Its limited statewide funding level, however, only begins to address the need to recruit and prepare larger numbers of minority teachers in mathematics and science in a state with an increasingly diverse student population.

Issues:

- Can this idea work in other states?
- Why has this program been successful thus far?
- What has been learned during this process of expansion?
- What has proved to be problematic?
- What is needed to implement a similar program?
- Who are the key players?

Presentation: Administrators of the original Eisenhower Pipeline project will discuss the implementation and expansion of the program. Audience will be given the opportunity to ask questions and provide comment.

Presenters:
Rex Fortune and Dorothy Retamer, Pipeline Mathematics and Science Academy
Valerie Iyala, Elk Grove Unified School District
Linda Barton White, California Postsecondary Education Commission

Group 15: The Engineering Education Coalitions: Models for Sharing Innovations In Undergraduate Engineering Education

The Engineering Education Coalitions, organized and active since 1990, have brought together 60 higher education institutions in eight Coalitions for the purpose of developing and implementing systemic, sustainable models of undergraduate engineering education reform. Institutional diversity allows the Coalitions to demonstrate adaptations to innovations with a view to scaleup by multiple institutions. From the beginning, a key goal of every Coalition was to assure that partner schools worked together to learn and share experiences in developing and implementing sustainable educational innovations. These changes are beginning to spread among and beyond the Coalitions.

Each Coalition includes diverse institutions (research universities, undergraduate institutions, small and large schools, historically black colleges and universities) working together in educational efforts that emphasize active student learning, use of interactive instructional technologies, and development of communication, teamwork, and leadership skills. Institutional diversity allows the Coalitions to demonstrate adaptations to innovations to a broad range of engineering schools.

Issues:

- What are the principal factors that make the Engineering Education Coalitions successful in spreading innovations and common goals?
- Who are the institutional participants and how can they be brought in to the adaptive process?
- What roles do faculty and administrative personnel play in developing, fostering, and replicating collaborative educational programs?
- Should undergraduate engineering education innovations be spread to feeder schools, for example, community and junior colleges, and how can this be accomplished?
- Should higher education collaborations be regional or national?
- What is required for adoption by others of successful engineering education models and innovations?

Presentation: Following a brief introduction on the background of the Engineering Education Coalitions Program, examples of successful dissemination of institutional innovations that originated within the Coalitions, a number of which have spread beyond their original borders, will be presented. These innovations include learning methodologies, team teaching and learning, broader understanding of societal needs related to engineering practice, lifelong learning, and diversity in engineering education and the engineering workplace. Presentations will be brief to allow maximum interaction among the presenters and session participants.

Presenters:

John W. Prados, NSF, Engineering Education and Centers Division (Moderator)
George Pincus, New Jersey Institute of Technology, Gateway Coalition
Thomas M. Regan, University of Maryland

Group 16: Comprehensive Regional Centers for Minorities and Urban Systemic Initiatives—Strategies for Successful Building

Three successful Comprehensive Regional Centers for Minorities (CRCM) have entered into broad-based partnerships with their respective Urban Systemic Initiatives (USI) cities. The CRCMs play an important role as "precursors" for the institutionalization of reform and exemplify a wide range of strategies for supporting and influencing USI reform efforts. These CRCMs have succeeded in identifying essential factors, key components, and elements that are critical for orchestrating systemic reform. Representatives from the selected CRCMs will provide examples to illustrate how they have been able to infuse their strategies into the education system and begin the process to scale up their methods to include a larger arena, i.e., an entire school district. USI representatives will provide overviews of the K–12 science, mathematics, and technology reforms that were built upon the CRCMs.

Issue: How can a city transform a project that is one essential portion of a broad systemic reform into full-blown, city-wide systemic initiative?

Presentation: This panel discussion will provide a forum for participants to discuss various models for infusing successful CRCM practices into the USI reform effort. A question-and-answer period will follow to allow for group interactions.

Presenters:
Roosevelt Calbert, NSF, Division of Human Resource Development (Moderator)
Madeleine Long, NSF, Office of Systemic Reform (Moderator)
Lloyd Cooke, LMC Associates
Eugene DeLoatch, Baltimore CRCM
Nora Ramirez, Phoenix Public Schools, USI
Dorothy Strong, Chicago USI

Group 17: Framing National Standards: A Closer Look at a Mathematics and Science Framework

The move to rethink education and educational practice is reflected in the Goals 2000: Educate America Act. One of the results of this initiative has been the creation of national discipline-based standards. National standards are intended to make it easier to determine what educators need to do to help students think and solve problems in today's competitive economy.

The Nebraska Department of Education, through a grant from the Eisenhower National Program for Mathematics and Science Education, funded by the U.S. Department of Education, is conducting a three-year statewide project to develop curriculum frameworks for K–12 mathematics and science education based on nationally recognized standards.

One of the goals of the Nebraska Board of Education is to provide the guidance needed to transfer these national standards into actual classroom practice. Curriculum framework documents are being developed to accomplish these tasks. The purpose of this session is to provide information concerning the role of national standards and state frameworks and to involve participants in demonstrating how the Nebraska Frameworks model is affecting state education.

Issues:

- Understand how frameworks facilitate the transfer of national standards into actual classroom practice
- Understand how standards and frameworks can promote "best practices" in K–12 systems
- Identify possible strategies for infusing mathematics and science education reform statewide

Presenters:

Ann Masters, Nebraska Department of Education
Catherine Wilcoxson, Nebraska Mathematics/Science Framework Project Coordinator
Judy Williams, Central City High School, Central City, Nebraska

Group 18: Expanding on the National Diffusion Network (NDN): How Two Science Projects Scaled Up from Origination Site to National and International Implementation

The expansion of two NDN science programs from their originating site to use in over 40 states and 12 foreign countries will be presented. The NDN is a program of the U.S. Department Education established to identify, validate, and disseminate exemplary educational programs by funding program developers and state facilitators to provide training and technical assistance to educators nationwide.

In addition to working with the NDN state facilitators, these developer/demonstrator projects have initiated a number of strategies that build on the base funding from the NDN to disseminate their practices nationwide. Strategies for scaling up that will be discussed include pre-implementation planning and decision making; developing and implementing effective teacher institutes; training local coordinators, administrators, and certified trainers; providing a wide variety of support services accessible by teachers on demand; collaborating with a nationwide consortium of universities to provide continual staff development and research; and networking with the Eisenhower Grants program Mathematics and Science Consortia at the national and state levels.

Internationally, scaling up has occurred through participation in professional association projects, resulting in their implementation in Australia, New Zealand, and International Schools in eight countries. Initiated through computer networking and participation in professional associations in telecommunications, Foundational Approaches in Science Teaching has been translated into Japanese, Russian, and Slovak. It is now the core of a new approach to science education in Russia, where five sites are working in school–university partnerships. In Slovakia, local teachers and university professors join together to provide inservice institutes and support for teachers. Continual collaboration with these international extensions provides new insights into science education which are then incorporated into the programs and staff development efforts.

Issues:

- Which strategies seem most effective? Which are least effective? Which are essential?
- Which strategies can be used by other projects?
- How can local adaptations and changes be accommodated?
- How can an extensive support system be maintained? What is the cost? Who are the key players?
- How can the problems of teacher turnover be addressed?
- What is the role of universities in the change process?
- What are the limitations? What has the success been in large cities? In rural areas?

Presentation: Presenters will discuss several of the key strategies that have been successful in scaling up. This will be followed by an open discussion with the session participants in a question and answer format to seek other successful strategies.

Presenters: Donald B. Young, Curriculum Research and Development Group,
University of Hawaii

THEME SESSIONS

Session I: 2:00 p.m. to 3:20 p.m.
Session II: 3:35 p.m. to 4:55 p.m.
Session III: 5:10 p.m. to 6:30 p.m.

SESSION I: 2:00 p.m. to 3:20 p.m.

Theme Session 1: Statewide Alignment, Coherence, and Coordination

This session is a follow-up to the morning break-out sessions on state curriculum frameworks and, especially, on the Statewide Systemic Initiative (SSI) program. Where the morning session discussed scale-up efforts in the context of the SSI program, this session will be devoted to working across programs from SSI to GOALS 2000, across agencies, levels of government, and disciplines. A panel of persons involved in both NSF SSI programs and ED GOALS 2000 programs, as well as other systemic efforts, will explore and explain opportunities for collaboration in the context of GOALS 2000 and the Improving the America's Schools Act. Panelists will briefly discuss ways in which they have addressed policy issues; territorial issues; partnership-building; teacher and administrators' professional growth; and parent, community, and public involvement and support.

Issues:

- Coordination with ongoing efforts (e.g., Goals 2000, Urban Systemic Initiatives) to minimize overlap
- Identification and filling of organizational gaps
- Strategies to maximize impact of the overall systemic effort
- Strategies for creating and sustaining collaborative agreements at the federal, state, and district levels
- Strategies for policy alignment, partnership building, teacher support, and building citizen ownership and support of systemic reform initiatives

Presentation: Panel presentations by SSI state representatives who are also involved in GOALS 2000 and other statewide educational reform initiatives, and in other SSI sessions at this conference.

Presenters:
Clare Gifford Banwart, ED, Office of Elementary and Secondary Education (Moderator)
Kerry Davidson, Louisiana
Thomas Keller, Maine
Richard Laughlin, Colorado
Teresa Staten, Michigan

SESSION II: 3:35 p.m. to 4:55 p.m.

Theme Session 2: Global Issues in Undergraduate Education

The contexts for science, mathematics, engineering, and technology (SMET) education have changed. NSF recognizes that major developments, such as the end of the cold war, intensified international competitiveness, the advance of technology, and the increased diversity of American society, require us to rethink strategies for undergraduate education. The recent White House document, *Science in the National Interest*, aptly expresses the challenge before us: "world leadership in basic science, mathematics, and engineering represents a critical long-term investment, one for which we need both vision and sound Federal policy."

NSF views undergraduate education as the linchpin connecting research to teaching, and school education to graduate education. That the principal federal effort in SMET education is in an agency devoted equally to research and education reflects the need for these efforts to be infused with knowledge and investigation. Of interest to NSF are 3,000 varied institutions that instruct 13 million American undergraduates. The specific targets of NSF action are all undergraduate students of SMET education and their instructors, with their diverse backgrounds and interests. We invite your thoughts on the reorientation of undergraduate education. The elementary questions are: what are the needs of this nation; what has been the response; and what should be the response?

Issues:

- Preparation and vitality of teachers and professors
- Scientific and technological literacy
- Means of promoting constructivist learning
- The industrial and business workforce
- The new generation of scientists and engineers
- Demographics, equity, and diversity
- Technology for and in instruction
- Special characteristics of disciplines
- Integration of research and education
- Comprehensive reform

Presentation: To be announced

Presenters:

Luther S. Williams, NSF, Directorate for Education and Human Resources
Robert Watson, NSF, Division of Undergraduate Education
Directorate for Education and Human Resources Advisory Committee Task Force for Study of Undergraduate Education
Melvin George, Chair
David Sanchez

SESSION III: 5:10 p.m. to 6:30 p.m.

Theme Session 3: Teachers: Recruitment/Induction/Retention/Continuing Education

Professional development is the bridge between where educators are today and where educators of the future will need to be. In order to ensure that students achieve higher standards of learning, educators must meet the challenges of mathematics and science education reform. High quality professional development emphasizes strategies that ensure career-long development of teachers and other educators whose competence, expectations, and actions influence school environments. These strategies include improving and integrating the recruitment, selection, preparation, initial licensing, induction, ongoing development, and support of educators.

Issues:

- Are there ways to convince the public that teaching is a professionally rewarding occupation? Teacher preparation and enhancement must reflect the nature of school change. How can this be reflected in school change?
- Teacher learning has all of the attributes of student learning. What would characterize a stance of critique and inquiry toward practice?
- How will we reach the multitude of teachers with an adequate amount of enhancement for successful reform implementation, both in cost and capacity?
- How do we provide teachers with enough time to discuss required changes brought about by new curricular materials?
- How do we help administrators provide the support teachers need?
- Measures of student outcomes too early in the processes of teacher development can easily derail even the best projects. How can accountability be built in early and not be dependent on student performance?

Presentation: This theme session will bring together experts from the morning sessions to discuss scale-up issues.

Presenters: To be announced

WORKSHOPS

Session I: 2:00 p.m. to 3:20 p.m.
Session II: 3:35 p.m. to 4:55 p.m.
Session III: 5:10 p.m. to 6:30 p.m.

SESSION I: 2:00 p.m. to 3:20 p.m.

Workshop 1.1: **The Boulder Valley Internet Project and Creating Connections**

Libby Black, Boulder Valley Public School District

The Boulder Valley School District and the University of Colorado are collaborating on a project to install Internet technology throughout the district and to train teachers and students in its use. The network is being used as a tool to support expanded educational reform and to integrate the community network and resources. To date, a core group of approximately 100 teachers has been trained (and are training others), community support and funding for placement of T1 Internet connections in all 47 schools in the district has been secured, and the community network is well underway. The project is, therefore, scaling up from pilot schools, to a whole school system, to the Boulder Community.

One of the ways in which we have shared our developing expertise in K–12 Internet training is through a project called "Creating Connections: Rural Teachers and the Internet." Through this project, funded by the Annenberg/CPB Math and Science Project and the US West Foundation, we have offered two-day Internet workshops on site nationwide to 450 rural math and science teachers. These teachers receive two years of support (on-line, 1–800, and FAX) to help them use the Internet in their professions.

Workshop 2.1: **A Network For Enhancing Middle Grades Mathematics Teachers Across Kentucky**

William Bush, University of Kentucky (Moderator)

Implementing mathematics reform in schools throughout a state is a daunting affair, so this project will provide support by scaling up levels of communication. The project has a statewide network, including school leaders and eight institutions of higher education, to provide intense staff development in mathematics education reform to every middle grades mathematics teacher in Kentucky by spring 1996. The workshop will examine the project materials, discuss barriers and solutions for such a statewide effort, and report on the implementation to date.

Workshop 3.1: **Philadelphia Science Resource Leaders for Middle Schools: Moving Toward Making an NSF Project Systemic in an Urban School District**

Lynnette Smith, Ambra Hook, and Gail Peddle, School District of Philadelphia

Though we are aware that the content of the 21st century and beyond cannot be fully identified, we recognize that Americans will need to know how to learn and apply skills needed to meet the challenges of a changing global society. What instructional and learning strategies lead to student achievement and how are they implemented? The educational reform movement is designed to instill in all students, regardless of college or job prospects, the skills and habits of mind to investigate problems and analyze information in a scientific manner. For graduates to be capable of these skills, the science curriculum and instructional strategies must emphasize investigative learning and application of concepts. Processes used to do science with students must reflect, to some extent, the practices of respected contemporary science. As we move into a new age, many of the required skills of the Industrial Age become obsolete. To be successful in the Information Age, we will need different skills, knowledge, and attitudes. This workshop will focus on practices that facilitate the growth of human potential in ways that will enable students to meet the challenges of the 21st century.

Workshop 4.1: Teacher Preparation: The Institutional Challenge

Institutional Presidents
James Lightbourne, NSF, Division of Undergraduate Education (Moderator)

The objective of the workshop is to solicit recommendations on the leadership role of chief executives in making teacher preparation a high priority of institutions and undergraduate education. A position paper will be developed to include the conclusions of the workshop.

Workshop 5.1: Teacher Preparation: A Cooperative Venture

Deans, Representing A & S, Education, Engineering
Tina Straley, NSF, Division of Undergraduate Education (Moderator)

A way to initiate systemwide change in education is to start at the root, the way teachers are prepared. The objective of this workshop is to solicit recommendations from deans on how to make teacher preparation an institutional, cooperative venture within undergraduate education. Issues to be examined include overcoming the barriers to engage science, mathematics, engineering, and education faculty in the recruitment and education of prospective K–12 teachers; making teacher preparation a priority of undergraduate science, mathematics, engineering, and technology education; developing a reward system to increase likelihood of faculty contribution to the preparation of future teachers; improving communication with community colleges in the preparation of teachers; and involving K–12 administrators and master teachers in the design and implementation of teacher preparation programs.

Workshop 6.1: Using Technology To Scale Up

Linda Stehr-Bopp, New York State Education Department, Office of Teaching
Martha Green, Florida Department of Education
Cynthia Pattison, Wisconsin Department of Public Instruction

Sixteen U.S. Department of Education Eisenhower grant projects are developing statewide curriculum frameworks consistent with high standards in mathematics and science. Several of the projects are using technology to build support for systemic reform, increase participation in the development of the frameworks, provide a bridge between the content of the curriculum and the organization and presentation of that content, and provide technical assistance to schools and teachers in implementing the frameworks.

Linda Stehr-Bopp will describe how New York's "Thinking Curriculum" video series builds awareness of the need to change across curricula and delivers instruction on staff development in implementing the state mathematics and science frameworks. Cynthia Pattison will discuss Wisconsin's use of the electronic superhighway to link the project's development teams, build statewide consensus, and share its framework with other states. Pattison will also discuss how an interactive compact disc project provides a vision of systemic reform for the larger community and addresses concerns of local control. Martha Green will explain how Floridian curriculum designers use the project's software to incorporate world-class standards and state frameworks into science classrooms.

Workshop 7.1: Implementing the Strategies Required to Teach to High Standards

Theron Blakeslee, Michigan Department of Education
John C. Cairns, Delaware Department of Public Instruction
Rebecca Christian, Louisiana Department of Education, Bureau of Pupil Accountability

The states of Michigan, Louisiana, and Delaware are three of the 16 recipients of U.S. Department of Education–Eisenhower Grant projects that are developing curriculum frameworks in mathematics and science. These projects will demonstrate new approaches to teaching and assessment as implied by the frameworks and explain how the states are assisting schools and districts to learn and implement these curriculum and teaching strategies. They will describe their efforts to engage local school districts in the planning processes for improving teaching and learning based on the standards, explain the processes being used to ensure that all teachers and students benefit from the reform effort, and discuss the impact that curriculum frameworks documents have on the reform of the mathematics and science curriculum, pedagogy, and assessment in the schools.

Workshop 8.1: Project Kaleidoscope

Jeanne Narum, Project Kaleidoscope
Stephen Good and Donald Deeds, Drury College

The aims and objectives of Project Kaleidoscope (PKAL) are to challenge people to:

- Ask the right questions in the process of reforming undergraduate programs in science, mathematics, engineering, and technology (SMET)
- Understand the kaleidoscopic nature of such reforms
- Work together as a community (on a single campus, between many campuses, with partners from the K-12 sector) in asking such questions and in moving from analysis to action, toward the goal of building an undergraduate SMET community that truly serves the national interest.

With NSF DUE funding, over the next two years PKAL will be hosting over 20 workshops on all aspects of reforming undergraduate SMET education. In this session, PKAL representatives will talk about how—through the process of application, permeating activities, intensive sessions during workshops, and explicit "take-home" assignments—the community of reformers can continue to grow, discussions about reform can continue to echo, and an ever growing community can be challenged to move to action.

Workshop 9.1: Using Database Dynamics for Systemic Reform

William McHenry, Costello Brown, and Tony Mitchell, NSF, Division of Human Resource Development (Moderators)
Harvest Collier, University of Missouri at Rolla
Tony Garcia, Arizona State University

This workshop will focus on elements that are critical for orchestrating systemic reform through database dynamics. Examples will be provided of how successful database systems have been able to "infuse the process and have demonstrated scaling-up approaches."

Workshop 10.1: Summer Science Camps

Betty Ruth Jones and Costello Brown, NSF, Division of Human Resource Development (Moderators)
Linda Cain, Oak Ridge Associated University
Laila Denoya, State University of New York, College of Fredonia
Bruce Munson, University of Minnesota-Duluth
Irvin Vance, Michigan State University, Black Child and Family Institute

This session will focus on the success of four Summer Science Camp projects. A critical assessment of what attributes are essential for implementing a successful residential, commuter, and combined residential and commuter project will be discussed with respect to infusion and scaling-up characterizations.

Workshop 11.1: **Blue Skies, National Geographic (NG) Kidsnet, and Common Knowledge: Pittsburgh**

Nora Sabelli, NSF, Division of Research, Evaluation and Dissemination (Moderator)
Perry Samson, University of Michigan
Bob Tinker, Technical Education Research Center
Richard Wertheimer, Pittsburgh Public School District

The projects presented will show how project-based, hands-on science activities at the K–12 level with the help of modern technology can be implemented and maintained in school districts of diverse types. The projects include Blue Skies, NG Kidsnet, and Common Knowledge: Pittsburgh.

Issues:
- Institutionalizing change
- Role of technology in enabling hands-on science activities
- Teacher support and ownership of change
- Criteria for making curriculum materials widely adoptable

In this workshop, each project director will present a multimedia synopsis of their project. The workshop will include hands-on learning time for participants and a question-and-answer period.

Workshop 12.1: **Project and Program Evaluation: Deciding what Strategies To Spread**

Daryl E. Chubin, NSF, Division of Research, Evaluation and Dissemination (Moderator)
Jim Dietz, NSF, Division of Research, Evaluation and Dissemination
Kenneth Maton, University of Maryland—Baltimore County
Charles Stalford, ED, Office of Educational Research and Improvement

This workshop will examine the process by which project and program evaluations are "translated" or distilled into the elements of strategies that can be disseminated or shared with the use of technical assistance.

Issues:
- What is generalizable from a single project evaluation? What inhibits or facilitates the spread of a success from one site to another (key individuals, receptivity of potential adopters, availability of resources and information)?
- Quality alone will not suffice in deciding whether an education project is adaptable or adoptable. What quality control methods are needed to determine what is "spreadable" from a project or program evaluation?
- Can evaluation help to delineate appropriate strategies for project dissemination, e.g., public awareness as opposed to technical assistance?

- Should components of scaleup or spread be built into every project or program evaluation? What are those components?
- Who should decide what actions are possible based on an evaluation or series of evaluations? Should all stakeholders be represented?

Brief presentations oriented to the questions above will be made by an evaluator, and two dissemination specialists. Exchange with workshop participants will be emphasized.

Workshop 13.1: Lessons Learned about Technical Assistance

Peirce Hammond, NSF, Office of Systemic Reform (Moderator)
Lloyd Cooke, LMC Associates
Floretta Dukes McKenzie, The McKenzie Group
Joy Frechtling, Westat
Myles Gordon, EDC
Mark St. John, Inverness Research Associates
Iris Weiss, Horizon Research

This session will discuss the crucial role of technical assistance to the systemic reform enterprise.

Issues:
- What constitutes technical assistance, and what assistance has been provided by statewide, urban, and rural systemic reform efforts?
- When should assistance be provided (in planning stage, redesign phase)?
- What are appropriate roles for NSF and contractors?
- What assistance is needed, what assistance is actually requested, and who determines the difference?
- What is the impact of technical assistance?

Workshop 14.1: Eisenhower National Clearinghouse (ENC) for Mathematics and Science Education

Len Simutis and John Salter, Eisenhower National Clearinghouse

This workshop will feature a demonstration of computer-network-accessible resources available through the Eisenhower National Clearinghouse (ENC) for K–12 mathematics and science education, including access to its *Catalog of Curriculum Resources*, the *Directory of Federal Programs*, and multimedia materials available in the ENC Digital Curriculum Laboratory and its World Wide Web server. A brief overview of additional resources to be made available in 1995 for on-line retrieval and on CD-ROM will be presented, with a particular emphasis on materials tied to reform efforts in math and science.

Workshop 15.1: Partnership Programs: Strategies for Systemic Reform

Ricardo Jacquez, New Mexico State University
Patricia Bready, University of Cincinnati
Joseph McDonald, Salish Kootenia College

This 90-minute workshop on partnership programs will focus on essential factors, key components, and elements that are critical for orchestrating successful partnerships which have led to strategies for systemic reform. A demonstration of critical roles successful partnerships have played in two programs, namely the Comprehensive Regional Centers for Minorities (CRCM) and the Alliances for Minority Participation (AMP) programs will be presented. Representatives from the following CRCMs and AMPs will be invited: New Mexico Highlands University, New Mexico State University, University of Cincinnati, City University of New York, and Montana State University.

SESSION II: 3:35 p.m. to 4:55 p.m.

National Network of Eisenhower Mathematics and Science Regional Consortia Workshops (Workshops 1.2–10.2)

These workshops will extend Eisenhower Regional Consortia by scaling up the distribution of information. Staff of the 10 Eisenhower Regional Consortia for Mathematics and Science will conduct a series of workshops that highlight their work with educators in promoting systemic reform, disseminating exemplary materials, and providing technical assistance in implementation and innovation. Participants will engage in hands-on sessions that will be highly interactive and filled with both informative and lively discussion. Technology at its best will be modeled, using such features as hypertext, audio and video clips, LCD panels, etc. Participants will be exposed to an array of resources, handouts, and valuable information about networking with others.

Workshop 1.2: **Powerful Change: Scaling Up with Promising Practices in Mathematics and Science**

SouthEastern Regional Vision for Education (SERVE) Mathematics and Science Regional Consortium

Join in this session to gain knowledge of how a leadership institute for scaling up provides an experiential context for understanding the role of promising practices in systemic reform in mathematics and science education. This presentation will feature a multimedia introduction on issues related to scaling up and a hands-on presentation by the developers of InTech (The Miami Museum of Science), a promising practice that serves as a collaborative link among four of the regional consortia.

Workshop 2.2: **Lessons in Professional Development**

Southwest Consortium for the Improvement of Mathematics and Science Teaching

Professional development has been a major focus of the work of this consortium. In this session, participants will interactively explore the components that must be included in effective professional development and share ideas about how to sustain such professional development in local schools.

Workshop 3.2: **Connecting Assessment with Curriculum Frameworks**

Eisenhower Regional Alliance for Mathematics and Science Education Reform

This project is scaling up the distribution of information from the Eisenhower Regional Alliance's study group. The study group is one of several major networks on key reform dimensions which the Alliance has launched. Participants will receive information on how to participate in any of these growing reform communities. During this interactive session, participants will experience some of the activities that members of the assessment study group have undertaken to foster widespread adoption of alternative assessment methods in mathematics and science K–12. Particular attention will be given to how assessment leaders can help with local implementation of curriculum frameworks.

Workshop 4.2: **Designing Integrative Learning Environments in Science and Mathematics**

Northwest Consortium for Mathematics and Science Education

This session will explore two broad models for the design of K–12 integrative learning environments: (1) the role of design in science and mathematics learning and (2) the effective use of community-based learning for promoting citizenship and achieving literacy in science and mathematics. Service learning and authentic forms of assessment will be highlighted.

Workshop 5.2: **Pathways: A School Improvement Resource System**

Midwest Consortium for Mathematics and Science Education

"Pathways" is an Internet-based resource tool designed to help schools obtain research, information, and resources so that they can improve learning in their schools in a systemic manner. Using hypertext, audio, and video allows users to find information easily on issues critical to schools. This presentation will review examples of those materials, provide explanations of why those materials are perceived as exemplary, and give suggestions as to where they fit within mathematics and science standards. Instructions will be provided on how and where these materials can be accessed and what equipment would be necessary.

Workshop 6.2: **Integrating Math, Science, and Assessment**

Appalachia Educational Laboratory Eisenhower Math and Science Consortium

This presentation is part of a successful workshop series developed in conjunction with the NSF-supported Virginia State Systemic Initiative (V-Quest) and Kentucky State Systemic Initiative (PRISM), and the Eisenhower Regional Consortia for Math and Science at Midcontinent Regional Educational Laboratory, the Eisenhower Regional Alliance for Mathematics and Science Education Reform, and the North Central Regional Educational Laboratory. This workshop walks participants through a hands-on set of learning experiences designed to provide participants with the knowledge, strategies, and successes needed to initiate change in classroom practice. The primary focus is creating connections within the curriculum and establishing assessment events articulated to the curriculum.

Workshop 7.2: **Connecting Across Disciplines and Distances through Authentic Tasks**

High Plains Consortium for Mathematics and Science

The richness of a multidimensional, interdisciplinary, authentic task provides students with an opportunity to be engaged, motivated, and creative. Add to that a context of distance learning, and you have a combination that is hard to beat. A model for developing authentic tasks, as well as several successful lessons, will be shared.

Workshop 8.2: **Alerting Assessment**

Far West Regional Consortium for Science and Mathematics

This workshop will provide experiences in using alternative assessment in science and mathematics. Participants will also explore the latest resources that are available both on-line and in hard-copy formats for using alternative assessments ranging from the classroom to the state level.

Workshop 9.2: **Supporting Ongoing Professional Development through the Internet: Forming Virtual Communities**

The Mid-Atlantic Eisenhower Consortium for Mathematics and Science Education

The Internet can provide powerful support for educators at all levels who are interested in reforming mathematics education. Educators in the mid-Atlantic region are collaborating with each other electronically to reflect on common experiences, share knowledge, and collectively solve problems in an effort to overcome many of the barriers to reform. By eliminating a teacher's sense of isolation, the Internet has helped to broaden and transform educational environments into exciting and idea-generating virtual communities. Come learn how to access important on-line resources with the RBS gopher. Become a part of an electronic network, and meet new colleagues.

Workshop 10.2: **Developing Partnerships and Local Empowerment for Success**

Pacific Mathematics and Science Regional Consortium

This session will explore the multidimensional effort to develop consensus and bring about scientific and mathematical literacy in a region covering millions of square miles with diverse cultures, languages, and levels of economic development. Particular attention will be given to the process that was used and to some of the products that have resulted.

Workshop 11.2: **The Hands-On Universe Project**

Carl R. Pennypacker, University of California, Berkeley (Moderator)

The Hands-On Universe, developed by professional astronomers and teachers, includes eight investigation units that enable students to analyze current and past images from remote telescopes linked through the Automated Supernova Search. Students investigate the mass of Jupiter by measuring the motion of one of its moons, measure spatial dimensions of the solar system, conduct collaborative searches for varying sources, plot light curves, and determine the distance to far-off objects. Telecommunications link students, teachers, and professionals in genuine collaborative interaction.

Workshop 12.2: **Project MASE (Mathematics and Science Enhancement)**

Project MASE is a four-year leadership project designed to restructure mathematics and science education for all K–6 students in the Clark County School district in Las Vegas. This is the largest school district in Nevada, serving over 60 percent of the K–12 students in the entire state. To accomplish reform on a large scale, every elementary teacher in the district must be reached for in-depth professional development in both mathematics and science. Enhanced pedagogical content knowledge and experiences of all the individual teachers will result in large-scale reform in mathematics and science education for all K–6 students in the entire district. The workshop is an example of a session that individual teachers in Project MASE might attend.

Workshop 13.2: **Mathematics through Applications Project**

Shelley Goldman (Moderator) and Jennifer Knudsen, Institute for Research on Learning, Stanford University

New models of teaching and learning bring an applications approach to work in middle school mathematics classrooms. Diverse classroom activities help students build stronger foundations for thinking and acting mathematically, and special activities address the needs of female, minority, and economically disadvantaged students.

Computer-based materials are introduced and new activity structures are used in which students use simulations adapted from real applications for learning mathematics. New teaching and assessment practices that use these materials are discussed, emphasizing teachers in collaborative working groups with students and helping students identify, analyze, and reflect upon the mathematical concepts and skills grounding their problems and their solutions.

Workshop 14.2: **Presidential Awardees: A Powerful Change Cadre**

Christine J. Comins, Pueblo, Colorado
Bonita Talbot-Wylie, Shorewood, Minnesota
Diane Wilson Burnett, Lafayette, Indiana

Expansion of knowledge in teaching excellence is the basis of this workshop. Meaningful science and mathematics programs are teacher dependent. Since 1983, over 1,600 awardees have been named for excellence in teaching at elementary and secondary school levels. These practitioners are doing what research is telling us must be done to reform mathematics and science programs; they are assuming leadership roles and are making a difference for students in classrooms throughout the nation. What lessons can be learned from them? How can we utilize their skills and talents in our reform efforts? These issues will be addressed through this workshop.

Workshop 15.2: **Using Common Knowledge: Pittsburgh as a Model for Technology Implementation Strategies in an Urban Setting**

Richard Wertheimer and Mario Zinga, Common Knowledge: Pittsburgh

The session will provide an opportunity to share the lessons learned by Common Knowledge: Pittsburgh (CK:P) while implementing networking technology in support of education reform. CK:P, one of the NSF-funded model networking implementation projects (or testbeds), is developing strategies to work with other urban schools districts.

Issues:

- The evolution of the CK:P project
- The learning curve regarding technical and organizational issues
- Characteristics of people in their organization that promoted change
- The nature of change in K–12 environments
- A forum for discourse on the process of institutionalizing technology
- Sharing experiences that are process, not product, oriented.

Workshop 16.2: **Computer Modeling**

Wally Feurzeig, Bolt, Beranek, and Newman

Case studies of representative examples of some of the best existing educational uses of computer modeling and visualization work will be presented to focus on ways to use modeling technology effectively to benefit pedagogy. The demonstrations will juxtapose several different approaches and tools to compare experiences in supporting student work with models in physics, chemistry, and biology. Exhibitors will discuss the capabilities and use several model development tools and applications, including Explorer Science, GenScope, ScienceWorks, and Stella. Hard-copy transcripts describing these modeling environments will be available.

SESSION III: 5:10 p.m. 6:30 p.m.

Workshop 1.3: **Developing and Using Number Sense**

Lorraine Blume, Keith Cochran, Las Vegas, Nevada

The session will focus on number relationships and mental computation. Participants will engage in a series of increasingly complex mental computation problems as presenters model how to help students generate their own procedures to solve computation problems mentally. Through video and hands-on experiences, participants will also be introduced to experiences that help primary school children begin to build an understanding of numbers relations that form the foundation for flexible manipulation of numbers. Recommended pedagogy will be modeled, and the philosophical basis of constructivism for children and adult learners discussed.

Workshop 2.3: **Issues-Oriented Science for Secondary Schools**

Herbert Thier, University of California, Berkeley (Moderator)

The Science Education for Public Understanding Program (SEPUP) is composed of one-year courses for middle and secondary schools. Expanding on the societal issues related to chemical usage within the Chemical Education for Public Understanding Program (CEPUP), the material moves into the life, earth, and physical sciences, as well as technology. SEPUP modules cover many of the large themes of science proposed in Project 2061, along with issues-oriented themes such as evidence-based decision-making, uncertainty and controversy, science, and social systems. As active participants, students are taught to become independent thinkers capable of understanding issues in science and technology. Materials include a teacher resource book, student text, project and extension activities, kits, videotapes, and software.

Workshop 3.3: **Project (UPDATE) Upgrading Practice through Design and Technology/Engineering Education**

Ronald D. Todd, Trenton State University (Moderator)

Project UPDATE is a model for innovative instruction and curriculum development efforts of teachers and professionals from the fields of science, mathematics, engineering, design, and technology. Its 12 curriculum packages targeting grades K–8 integrate mathematics, science, and technology and focus on design, technology, and problem solving. National dissemination of the models and materials is accomplished through regional teacher training institutions and *TIES Magazine*—a free periodical for teachers published at Trenton State University.

Workshop 4.3: **Mathematics in Context: A Connected Curriculum for Grades 5–8**

Tom Romberg, Wisconsin Center for Education Research

Classroom approaches that depend on discourse and interaction among students, curricula that treat content in an integrated or interconnected manner, and new assessment approaches place new demands on teachers. This project, developed through a collaborative arrangement between the University of Wisconsin and the Freudenthal Institute in the Netherlands, addresses these issues and is aligned with the National Council of Teachers of Mathematics (NCTM) *Curriculum and Evaluation Standards for School Mathematics* and *Professional Standards for Teaching Mathematics*. The 40 units connect the mathematical strands of number (common fractions, ratio, decimal fractions, percents, integers), geometry (measurement, synthetic geometry, coordinate and transformation geometry), statistics and probability (the language of chance, distribution and variability, and quantifying expectations), and algebra (patterns and functions). Each set of grade-level units engages students over a range of ability levels. This session will deal with what the challenges are to nationwide implementation.

Workshop 5.3: **K-12 and the Science, Mathematics, Engineering, and Technology Education Undergraduate Program**

Judith Ramaley, President, Portland State University
Emma Owens, NSF, Division of Elementary, Secondary and Informal Education
Herbert H. Richtol, NSF, Division of Undergraduate Education

What courses of action should the be taken in order to prepare students who will shortly be ready to enter college and have been educated using significantly different pedagogies and course content strategies? This challenge is particularly pertinent for academic deans, who need to set directions in their schools to meet this challenge. Issues discussed in this workshop include elaborating the requirements of colleges to meet this challenge; plans deans and NSF can make to enable colleges to educate the new and diverse student body; successfully and how NSF should begin to address this issue.

Workshop 6.3: **Undergraduate Programs and Systemics**

Robert Swenson, Montana State University
Terry Woodin and Elizabeth Teles, NSF, Division of Undergraduate Education
Carolyn Mahoney, NSF, Office of Systemic Reform

Systemic reform efforts have resulted in exciting changes in state attitudes and standards for science, mathematics, engineering, and technology education. This session will explore the effect of these changes on undergraduate education, particularly as regards teacher preparation, the technical workforce, and the contribution of undergraduate education to the reform effort.

Workshop 7.3: **The Role of Science, Mathematics, Engineering, and Technology Education Research Faculty in the Undergraduate Enterprise**

A leader in Education and Research, NSF Staff from the Division of Undergraduate Education, and a Research Directorate

What responsibility do research faculty have for improving the scientific literacy of all students? In order to answer this broad question, workshop participants will be asked to explore the ways research and undergraduate teaching are symbiotic and parasitic and how universities should structure the system through which faculty are evaluated, recognized, and rewarded to achieve a balance between research and undergraduate teaching. Participants will also focus on how NSF should support research and education to promote optimal faculty productivity and, for undergraduate curricula, the optimal balance among in-depth training in one discipline, training across a range of scientific disciplines, interdisciplinary study, and the humanities.

Workshop 8.3: **Preparing a New Generation of Undergraduate Faculty: Role of Graduate Programs**

Jay Labov, National Research Council
Gordon Uno, University of Oklahoma
Norman Fortenberry, NSF, Division of Undergraduate Education
NSF Staff members from the Division of Graduate Education and Research Development

More than ever, undergraduate institutions are experiencing pressure to respond to challenges facing the nation, such as the need to remain competitive in an increasingly global economy and to develop a workforce that is technologically competent and a citizenry capable of making informed judgments about the uses and products of science. As undergraduate programs direct their attention to curricular and pedagogical initiatives that will enable them to meet these and other challenges to education, their concerns will be reflected in their hiring criteria. Are SMET education graduate programs currently training teaching assistants and educating students to function effectively as undergraduate faculty within the new national climate? What can graduate schools do to facilitate the transition between graduate training and undergraduate instructional needs?

Workshop 9.3: **Implementing the Science Standards**

Richard Klausner, National Committee on Science Education Standards and Assessment
Representatives from states/districts

The National Academy of Sciences has recently released the prepublication draft of the science standards, with the final version to be completed later in 1995. This workshop will focus on implementing the standards at the state and district levels and will provide an opportunity to discuss exemplars of good practice in elementary, middle, and high schools.

Workshop 10.3: Preview of the 1994 Mathematics and Science Education Indicators

Larry Suter, NSF, Division of Research, Evaluation and Dissemination (Moderator)
Dan Koretz, RAND Corporation
Terrence Russell, Association for Institutional Research
Iris Weiss, Horizon Research

This workshop will review evidence from national surveys about the changes during the past 20 years in student achievement, student course choices, and teacher practices. Participants will examine the significance of national trends toward higher levels of mathematics and science achievement in the United States.

Issues:
- Do the trends displayed in this report suggest that a new consensus has been reached in the United States on changes that are needed in elementary and secondary schools in order to improve their level of performance?
- What topics of major concern to policy making at the national, state, and city level are not addressed by the statistical series shown in this report?
- Are special surveys needed for NSF evaluation of national trends?

The workshop will feature a selection of graphics indicating large changes underway in student achievement, student completion of science courses, teacher practices in classrooms, and the transition to college. Panel members will examine these trends and open the floor for discussion of the implications for national policy.

Workshop 11.3: Mosaic, World Wide Web, Internet, and AskERIC

Barbara Mihalas (Moderator) and Jeff Graber, NSF, Division of Research, Evaluation and Dissemination
Department of Education representative

The Internet and its associated development environment, the World Wide Web, enable teachers and students to present, retrieve, and share information electronically between computer systems. This workshop brings together a few of the investigators in this area to demonstrate the implications and challenges facing educators in the use of the Internet.

Issues:
- Effective use of the technology
- Dissemination strategies
- Models of excellence (NSF-selected projects and AskERIC)
- Product evaluation (Mosaic and AskERIC)

- Integration of technology into curriculum
- Media and multimedia dimensions and hands-on learning

In this workshop, groups will discuss handouts prepared by Jeff Graber on areas to access the WWW through Mosaic.

Workshop 12.3: Lessons Learned from the Rural Systemic Initiative

Jody Chase, NSF, Office of Systemic Reform (Moderator)
Vicente LLamas, New Mexico Highlands University
Carty Monette, Turtle Mountain Community College
Paul Ohme, Northeast Louisiana University
Wimberly Royster, Kentucky Science and Technology Council

The Rural Systemic Initiatives (RSI) program is focused on improvements in science, mathematics, engineering, and technology (SMET) education for students in rural, economically disadvantaged regions of the nation. RSI is tailored to address policy, leadership, and workforce issues related to educational barriers and to bring together community involvement and related educational and technological innovations to provide a comprehensive and sustainable framework for SMET instruction in elementary, secondary, and higher education. The workshop will discuss coalition-building, partnering, and cooperative arrangements, as well as resource allocation in a multistate or multitribal initiative. It will explore information gleaned about systemic reform in rural areas and will discuss similarities and differences in approaches and strategies among the various programs.

Workshop 13.3: Lessons Learned from the Statewide Systemic Initiative

Janice Earle, NSF, Office of Systemic Reform (Moderator)
Kerry Davidson, Louisiana
Helen Foss, Delaware
Richard Laughlin, Colorado

The Statewide Systemic Initiatives (SSI), established in 1990, supports 24 states and Puerto Rico in making comprehensive improvements in science, mathematics, engineering, and technology education through systemic changes in state education systems. This session will discuss critical issues from the SSI enterprise, such as governance, partnerships, implementive visions of good practice, evaluation, and state context, by exploring evaluation reports, case studies, and anecdotes.

Workshop 14.3: Lessons Learned from the Urban Systemic Initiative

Paula Duckett, NSF, Office of Systemic Reform (Moderator)
Phyllis Cohen, Dade County, Florida
Cal Smith, Cincinnati, Ohio
Maurice Sykes, Washington, D.C.

The Urban Systemic Initiatives (USI) targets the 25 cities with the largest numbers of school-age children living in poverty and challenges urban school districts to reform their science and mathematics programs to provide high-quality education in these areas for all students. Established in 1992, the USI program began by awarding planning grants to eligible cities. Although cooperative agreements for the first implementation grants were awarded in the fall of 1994, the program has had significant impact already at this early date. In this session, the lessons learned from the program to date will be shared and discussed.

Workshop 15.3: Business, Industry, and Education Interactions

Ed Bales, Motorola Corporation
Richard Lengyel, Boeing Company

Representatives from industry will discuss their corporations' relationship to major education initiatives. Attendees at this workshop will consider examples from the industry representatives, share other related activities, and develop strategies for education and industry cooperation.

Workshop 16.3: Project 2061: Using *Benchmarks for Science Literacy* to Choose Instructional Materials

Mary Ann Brearton and Koralleen Stavish, Project 2061

Clearly defined goals for learning imply that curriculum materials should be chosen on the basis of how well they contribute to the specified goals. Many otherwise high-quality materials currently on the market seem unlikely to satisfy such evaluation. Participants in this workshop will be guided in using Project 2061's *Benchmarks for Science Literacy* and *Benchmarks* on disk in judging the utility of currently popular materials for teaching literacy in science, mathematics, and technology.

EXHIBITS

Exhibit 1: **Rhythm**

Sally Osberg, Children's Discovery Museum of San Jose

Developed and built by the Children's Discovery Museum of San Jose, California, with support from NSF, the Seaver Institute, and Apple Computer, the Rhythm exhibition totals 12 units. Together, these exhibits explore a range of rhythmic phenomena from the familiar clip-clop of a galloping horse and the beat of one's own heart to the less familiar resonance of a standing wave. Highly interactive, the exhibits offer their audience a broad range of access points *Rhythms of Traffic*, for example, succeeds in engaging toddlers, who happily snap cables into place, as well as engineers, who push the exhibit into an oscillation mode. Graphic panels tell the Rhythm story, from Eadweard Muybridge's famous galloping horse photography experiment to exhibit developer Tom Nielsen's childhood fascination with relay clocks that govern traffic signals. Introductory graphic panels are built into the unit housing the *Soundscapes* exhibit.

Exhibit 2: **Patterns in Nature: A New Approach to Interdisciplinary Science**

Gerald Abegg, Kenneth Brecher, and Peter Garik, Boston University

The Patterns in Nature: A New Approach to Interdisciplinary Science project introduces and prepares teachers to use the materials developed at the Boston University Center for Polymer Studies and Science and Mathematics Education Center. The project prepares teachers to be mentors in a cooperative learning classroom environment in which students learn science from performing experiments and interacting with their peers and with computers, rather than learning exclusively from the teacher.

The scientific content of these educational materials comes largely from our scientific research. Current research, which we have adapted to high school science classes, includes molecular networks and the growth of random fractal structures. This leading-edge research is usable in high schools because of the simplicity of the rules embedded in the physical models, the availability of computers to apply these models to large systems, and the ease with which students successfully manipulate the resulting interactive visual displays.

Exhibit 3: **Image Processing for Teaching**

Richard Greenberg and Robert Kolvoord, University of Arizona
Melanie Magisos, Center for Image Processing in Education

The Image Processing for Teaching project provides a powerful medium to excite students about science and mathematics, especially those from minority groups and those whose needs have not been met by traditional "coded" ways of teaching these subjects, while offering open-ended opportunities for exploration, discovery, and quantitative analysis. We have developed curriculum materials in all areas of mathematics and science for the upper elementary school through college levels, allowing this tool to be used across a variety of subjects and student interests. Through workshops run by the Center for Image Processing in Education (CIPE), teachers learn image processing and how it can be incorporated into their classes. CIPE provides materials, implementation support, and teacher education for school districts, colleges, and other education projects that want to incorporate image processing into their educational programs.

Exhibit 4:

Creating Connections: The Boulder Valley Internet Project

Libby Black, Boulder Valley Public School District

The Boulder Valley School District and the University of Colorado have initiated a collaborative project to install Internet technology throughout the district, train teachers and students in its use, explore the use of the network as a tool to support educational reform, and integrate a community network into the project.

A core group of approximately 100 teachers has been trained (and are training others); community support and funding for placement of T1 Internet connections in all 47 schools in the district has been secured; and the community network is well underway. The project is, therefore, scaling up in many respects. One of the ways in which we have shared our developing expertise in K–12 Internet training is through the project "Creating Connections: Rural Teachers and the Internet." Through this project, funded by the Annenberg/CPB Math and Science Project and the US West Foundation, we have offered a two-day Internet workshop to 450 rural math and science teachers. These teachers will receive two years of support (on-line, 1-800, and FAX) to help them utilize the Internet in their professional lives.

Exhibit 5:

Presidential Awards Program

Presidential Awards recipients will share what they have learned, what has happened since being selected as an awardee, and how they are helping in the improvement of mathematics and science education. The awardees will discuss their use of Internet and other computer programs. The awardees participated in an NSF computer workshop in North Carolina this past summer and can provide insights on how to help other teachers access networks.

Exhibit 6:

Mathematics through Applications Project

Shelley Goldman and Jennifer Knudsen, Institute for Research on Learning, Stanford University

This project is developing an applications-based curriculum, which includes long-term activities and simulations, for middle school students. Such activities require applying the mathematical modeling process to real-world problem situations through projects requiring regular use of technology. The project developers are working with Sandia National Laboratory engineers and others to create relevant project activities that incorporate significant aspects of engineer and scientist work practices.

Exhibit 7:

Educational Resources Information Center Clearinghouse for Science, Mathematics, and Environmental Education (ERIC/CSMEE)

David Haury, J. Eric Bush, and Allison Benjamin, ERIC/CSMEE

The Educational Resources Information Center (ERIC) is a nationwide information system that has developed the world's largest education-related database and an extensive array of electronic services for educators at all levels. The ERIC Clearinghouse for Science, Mathematics, and Environmental Education (ERIC/CSMEE) is one of 16 clearinghouses funded by the U.S. Department of Education that collect, abstract, and index materials for the database. The Clearinghouse also publishes and disseminates documents on current research, programs, and practices in science, mathematics, engineering, and technology (SMET) education; provides a variety of electronic services through the Internet; and generally facilitates improved teaching, learning, research, and scholarship through the active exchange of information and services.

In addition to demonstrating use of the ERIC database, the exhibit will highlight the electronic services of the Clearinghouse and the ERIC system, the dissemination and distribution of support services provided by the Clearinghouse, partnership arrangements, and publications. The Clearinghouse maintains a Gopher server on the Internet that provides direct access to full-text documents, information of particular interest to SMET educators, and pointers to many services on the Internet. The Clearinghouse is prepared to demonstrate ERIC database searches, Clearinghouse Gopher site searches, and World Wide Web services provided by the Clearinghouse and the ERIC system. It will also display a variety of publications available through the distribution office, and Clearinghouse staff members will be on hand to describe partnership activities and other available collaborative arrangements.

Exhibit 8:

Full Option Science System—Comprehensive K–6 Curriculum

Lawrence F. Lowery, University of California, Berkeley

Commanding a 15-percent market share nationwide and a 62-percent market share in California, Full Option Science System (FOSS) has greatly improved science, mathematics, and technology education for K-6 students through hands-on learning. In its first few years of dissemination, it has met with enormous enthusiasm in Norway, Puerto Rico, and the former Czechoslovakia. Guided by a common philosophy and theory of cognitive development, FOSS is a comprehensive, developmentally sound program accessible to a broad range of teachers. The complete curriculum features 27 topical modules covering the life, physical, and earth sciences, as well as scientific reasoning and technology. The multisensory activities are technically and developmentally appropriate for all students at relevant grade levels.

Exhibit 9:

Activities and Readings in the Geography of the United States—Innovative Standards-Based Curriculum To Understand the Environment

Osa Brand, Association of American Geographers

Leading geographers from the Association of American Geographers, together with secondary school teachers, have produced a curriculum materials package for use in existing and emerging social science classes in secondary schools. The materials focus on population patterns, economic regionalization and political geography as factors that shape the pattern of human–environment interaction throughout the nation. The aim of these materials is a broad contextual understanding of environmental issues, with particular emphasis on the kinds of global problems that require coordinated action at the global, regional, and local levels. The materials consist of a concise geography text, a set of classroom and individual student activities, related readings, and a detailed teachers manual. Student assessment instruments are also developed. The materials incorporate features that reflect trends in several aspects of the secondary curriculum as recommended by "Guidelines for Geographic Education," the *NCTM Standards*, and "Charting a Course: Social Studies Curriculum for the 21st Century" published by the National Commission on Social Studies in Schools.

Exhibit 10:

Issues-Oriented Science for Secondary Schools

Herbert Thier, University of California, Berkeley

The Science Education for Public Understanding Program (SEPUP) is comprised of one-year courses for middle and secondary school. Expanding on the societal issues related to chemical usage within the Chemical Education for Public Understanding Program (CEPUP), the material moves into the life, earth, and physical sciences, as well as technology. SEPUP modules cover many of the large themes of science proposed in Project 2061, along with issues-oriented themes such as evidence-based decision-making, uncertainty and controversy, science, and social systems. As active participants, students are taught to become independent thinkers capable of understanding issues in science and technology. Materials include a teacher resource book, student text, project and extension activities, kits, videotapes, and software.

Exhibit 11:

The Hands-On Universe Project

Carl R. Pennypacker, University of California, Berkeley

The Hands-On Universe project, developed by professional astronomers and teachers, includes eight investigations that enable students to analyze current and past images from remote telescopes linked through the Automated Supernova Search. Through the project, students investigate the mass of Jupiter by measuring the motion of one of its moons, measure spatial dimensions of the solar system, conduct collaborative searches for varying sources, plot light curves, and determine the distance to far-off objects. Activities, intended for high school astronomy, physics, or physical science courses, include hands-on investigations that lead to in-depth scientific research using powerful technological tools. Telecommunications link students, teachers, and professionals in genuine collaborative interaction.

Exhibit 12:

Project (UPDATE) Upgrading Practice through Design and Technology/Engineering Education

Ronald D. Todd, Trenton State College

Project UPDATE is a model for innovative instruction and curriculum development efforts for teachers and professionals from the fields of science, mathematics, engineering, design, and technology. Its 12 curriculum packages, targeting grades K–8, integrate mathematics, science, and technology and focus on design, technology, and problem solving. National dissemination of the models and materials is accomplished through regional teacher-training institutions and *TIES Magazine*—a free periodical for teachers published at Trenton State.

Exhibit 13:

MAGIC SCHOOL BUS

Cheryl Gotthelf, Scholastic Productions
Michael Templeton, Consultant, Portland, Oregon
Beverly Sanford, Discovery Place, Inc.

The MAGIC SCHOOL BUS is a project that builds on the joint endeavors of two separate grants—one to Scholastic Productions for a fully animated television series based on the popular series of science books of the same name and one to Discovery Place, Inc., on behalf of the MAGIC SCHOOL BUS Museum Collaborative, to develop educational materials and exhibits that capitalize on the interest and excitement of the MAGIC SCHOOL BUS television series.

The television program presents science through dramatic stories told with humor and excitement. Since it draws upon the characters and style of the books, the television series will have a ready-made audience that will eagerly seek more adventures of Ms. Frizzle and her class. Ms. Frizzle's message to her television students is that they all are able to succeed in science, regardless of gender or ethnicity. Every child in the audience will find a character to identify with, and like the students on the screen, will get caught up in Ms. Frizzle's dynamic brand of pedagogy. In addition to the series, Scholastic Productions has developed support material for teachers to encourage supplemental use of the series in the classroom.

To support the series and to get youth engaged in science activities, the Discovery Place Museum and its partners have created two copies of a 1,200-square-foot traveling exhibit, a museum activity/program trunk, and an activity and programming guide for youth groups. The collaborative also works directly with eight national youth-serving organizations to encourage multiethnic participation in science activities programs. The museum trunk is being used by more than 70 youth museums and science centers nationwide to engage young visitors in hands-on science activities related to the book.

Promotion for the project includes public relations efforts provided by the Public Broadcasting Service, which broadcasts the series nationally, as well as information dissemination to youth, teachers, and parents through the numerous Scholastic, Inc., educational publications. Scholastic, Inc., publishes eight magazines, which reach approximately 4.5 million children. Outreach material to students will be distributed by placing stories and activity pages in these magazines. In addition, McDonalds has adopted the MAGIC SCHOOL BUS as one of its major promotional efforts and featured the project in all of its restaurants and in *Fun Times*—a youth magazine available in English and Spanish—in the fall of 1994.

Exhibit 14: GALAXY Classroom

Walt Hindenlang, GALAXY Classroom

This project has developed a systematic science enrichment program for elementary students that strengthens curriculum through the development of video-based supplementary educational materials distributed through an interactive satellite network. The program focuses on integrated classroom activities and a strong enhancement program for teachers, administrators, and parents. The project includes two 13-part science video programs (closed captioned, Spanish track) for grades K–2 and 3–5, and comparable programs for English-language arts. GALAXY classroom has been field tested in 40 representative urban and rural elementary schools in the United States (and one in Mexico).

The exhibit will include: (1) presentation of the science video program; (2) samples of the classroom curriculum materials in English and Spanish; (3) samples of hands-on science materials; and (4) curriculum evaluation reports.

Exhibit 15: Science, Engineering, and Technology Careers

Solomon Garfunkel, COMAP, Inc.
Steve Rabin, Educational Film Center

The Science, Engineering, and Technology (SET) careers exhibit, designed for distribution to science museums, technology centers, libraries, schools, and other community sites, is a collaborative effort between the Educational Film Center, the New York Hall of Science, the Consortium for Mathematics and Its Applications, and the American Association for the Advancement of Science.

The core of the exhibit kiosk is SET/QUEST, an interactive multimedia program for both the Macintosh and PC/Windows. Participants explore 30 careers through first-person video profiles of people in science and engineering fields, animated/reality video simulations of a work experience in these fields, decision screens, and a database of more than 200 science and math-based professions. Documentary profiles, a database, and a personal-interest career-match component are available in alternative media formats (video, audio, print). Specific emphasis in this project is being placed on reaching and attracting young women, minorities, and disabled youth.

A parent outreach component has been developed to work directly with and through the offices of four major national organizations. This aspect provides parents and families with information they can use to help foster their children's pursuit of science and math education and careers in these fields.

Exhibit 16:

"Bill Nye, the Science Guy"

Bill Nye and Pam Fajita-Yuhas, KCTS

"Bill Nye, the Science Guy" is a series of weekly science education programs for children. The series is by KCTS in Seattle, Washington, and is broadcast on PBS as well as being syndicated nationally by Buena Vista Films, a division of Walt Disney Productions. The goals of the series are (1) to make science accessible and interesting to children in the fourth and fifth grades by relating science to the interests and everyday activities of children and (2) to present basic concepts from elementary science curricula in a humorous and exciting format. The program's host, Bill Nye, conducts demonstrations and experiments in a variety of studio and field locations. Each program features a diverse cast of children, scientists, and celebrity guests. The experiments can be conducted at home or in school using inexpensive, safe, household items. Ancillary and outreach components include a science activity kit for use in fourth grade classes, a home activity kit, and an urban center project in Los Angeles.

Exhibit 17:

Teacher to Teacher with Mr. Wizard

Denis Harlan, Mr. Wizard Foundation

This project's major goal is to show thousands of elementary teachers how successful hands-on, inquiry-based science can work in their classrooms. To accomplish this, the project will produce 50 15-minute programs (hosted by Don Herbert) to be aired on Nickelodeon. Unlimited off-air taping and duplication rights will allow teachers to view programs at their convenience and to make copies for their colleagues. A newsletter about the programs will be sent to more than 70,000 schools and the program supplement will be distributed on-line by CompuServe, America Online, Prodigy, and Xchange.

Exhibit 18:

Everyday Mathematics 4–6: A Curriculum for Fourth- through Sixth-Grade Students with Substantial K–3 Prerequisites

Max Bell, University of Chicago School Mathematics Project (UCSMP)

Everyday Mathematics 4–6 provides a complete reform program in mathematics for grades 4–6, continuing the development begun in Everyday Mathematics K–3.

Instruction in Everyday Mathematics is based on whole-class and small-group discussions and hands-on activities. Students experiment, observe, research, make and test hypotheses, draw conclusions, and record and report their findings for further discussion. Everyday Mathematics 4–6 blends mathematical strands (numeration, operations, geometry, measurement, data, mathematical modeling, etc.) with themes such as science, geography, sports, and architecture.

Components for teachers include teachers manuals, lesson guides, and reference books. Components for students include student journals (booklets that provide lesson information, instruction, questions, and a permanent place to record conjectures and results), MathLinks (follow-up activities to be done in the classroom or at home), and Project Books (year-long projects). Everyday Mathematics 4–6 will be used in classrooms for a full year and revised for publication on the basis of the results.

UCSMP was closely involved with 13 fourth-grade classrooms in Illinois, Massachusetts, New Jersey, and Pennsylvania during the 1993–94 school year. In addition to these sites, approximately 300 classrooms used materials under the direction of the project's publisher, Everyday Learning Corporation.

Exhibit 19:

PRIME Science

Penny Moore, University of California, Berkeley

PRIME Science provides an American adaptation of Salter's Science—a well-tested, multidisciplinary science and technology program for middle grades developed in Great Britain. In a total of 40 units, the program addresses the life, earth, and physical sciences; develops conceptual understanding; and integrates mathematics, technology, and decision-making. The teachers' guides are directed at first year teachers not teaching in their major discipline. Included are student preconceptions, safety, background, and ways of introducing the content and assessment items. Visually stimulating student supplements provide summaries of what students should know and what they need to learn, and the activities they can perform. The materials are tested and rewritten by teachers and science educators at several sites throughout the United States. Professors at the University of California, Berkeley review the materials for content accuracy. The British developers are part of the design team.

Exhibit 20: **Event-Based Science: An Earth Science Curriculum**

Wayne A. Moyer and Russell G. Wright, Montgomery County (MD) Public Schools (MCPS)

This project develops a year-long, event-based earth science curriculum for middle school students. The materials include modular text, a teacher resource notebook, and videotape and/or videodisc support. The project focuses on the following instructional approaches: (1) it is topical and relevant to early adolescents; (2) the interdisciplinary nature of this event focus is enhanced by the collaboration between project writers and teacher and consultant panels; (3) students are involved in the development of the materials; (4) it stresses alternative assessment techniques and grading strategies, which reward success and downplay failure; (5) it utilizes the news media as one source; and (6) it is a national project developed as a collaborative effort of MCPS, the U.S. Government, and professional and news agencies.

Exhibit 21: **Young Scholars Program at Purdue University**

Christian Y. Oseto, Jennifer Stewart, Rochelle Stansberry, and Enriqua Luna, Purdue University

The Purdue University Young Scholars Program provides an enriching experience in agricultural and environmental sciences for students completing their junior year in high school. At the NSF Invitational Conference, three students will present a poster session on their research projects that focus on environmental issues pertinent to the food sciences, agricultural, and natural resources disciplines. They will share their individual research experiences through a discussion of their projects followed by a question-and-answer session. The presenters will also provide insight on how the experience has influenced their interest toward careers in science.

Exhibit 22: **Project Atmosphere**

Ira Geer, American Meteorological Society

Project Atmosphere brings together information on the sun, sky, clouds, wind, rain, and satellites, with a permanent network of Atmospheric Education Resource Agents (AERAs). This project, in conjunction with the American Meteorological Society, encourages teachers in grades 5–9 to use the atmospheric environment to heighten students' interest in science and to add relevancy to their education. An extensive training program, followed by annual renewal sessions, will produce a steady-state network of 80 AERAs.

Teacher enhancement materials include 200 reference and resource papers on atmospheric environment topics, an annual newsletter, and 10 self-contained instructional modules. Participants learn how to access large amounts of weather service satellite data for classroom use. This "datastreme" is delivered to the participants' classroom over the vertical blanking interval of the Weather Channel on cable television. AERAs train their peers to use these materials and the datastreme in workshops they conduct.

Exhibit 23: **Project TEA and SEA**

April Lloyd, The Barn

Teachers Experiencing the Antarctic (TEA) and Students Experiencing the Antarctic (SEA) bring together five teachers, five students, and five Antarctic research scientists for a research experience "on the ice." Teachers and students are nominated through their interactions with a Teacher Enhancement project, a Comprehensive Research Center for Minorities project, or the Young Scholars program. The competitive program enables a teacher and student to work with an Antarctic scientist in the laboratory for a two-week period during the summer prior to a research experience on the ice. The on-site research experience varies from two to seven weeks and occurs during the austral summer. Following the Antarctic research experience, teachers are expected to infuse their knowledge into their curriculum.

Exhibit 24: **Mathematics in Context: A Connected Curriculum for Grades 5–8**

Tom Romberg, Wisconsin Center for Education Research

Mathematics in Context: A Connected Curriculum for Grades 5–8 is a 40-unit curriculum designed to align with the *National Council of Teachers of Mathematics (NCTM) Curriculum and Evaluation Standards for School Mathematics* (1987) and the *NCTM Professional Standards for Teaching Mathematics* (1991). Mathematics in Context is being developed for middle school grades through a collaborative arrangement between the University of Wisconsin and the Freudenthal Institute in the Netherlands. Each of the 40 units explains mathematical concepts in a way that is realistic and meaningful to students. Each set of grade-level units is developed to engage students over a range of ability levels. Teachers guides are used to guide student learning and to help teachers cope with open-ended learning situations that may result in more than one "right" answer.

During the development of the curriculum, pilot versions of individual units were tested in classrooms located in Wisconsin, Missouri, and Iowa. A full field test of the curriculum will occur during the 1994–1995 academic year in selected schools in Tennessee, California, Missouri, Iowa, and Wisconsin. Spanish versions of the units will be used in conjunction with a field test in Culver City, California. The publisher will also test the curriculum in Florida, California, and Puerto Rico during 1994–1995.

Encyclopedia Britannica will publish the 40-unit middle school curriculum, related teachers guides, and management materials beginning in late 1995.

Exhibit 25:

Technology-Based Learning: Exploring Statistical Concepts and Methods

William Notz, Ohio State University

The main products of this project are an electronic encyclopedia of statistical examples and exercises (EEEE), and an electronic data archive. The prototype EEEE is being written in Hypercard for use on a Macintosh computer. The prototype includes approximately 50 examples, drawn from a wide range of subject matter areas, with more than 800 pages. The EEEE prototype presents a synopsis of each problem, a description of the data, visual aids—including pictures, maps, and video clips—a bank of questions pertaining to the problem, solutions to those problems, subject matter references, and statistical references. Users of EEEE can call up additional information, analyze the data, and get ideas for further analysis. Statistics faculty at Ohio State University are using EEEE as a resource for lectures, exam problems, and the development of a self-paced course in statistical concepts.

Exhibit 26:

Calculus Reform Exhibit

Representatives from calculus projects and NSF staff

With NSF support, several approaches to improving calculus instruction have been developed. The calculus reform movement is having a national impact, with an estimated 37 percent of all calculus students now taking calculus in a reformed course. The exhibit presents the materials and software developed in several NSF-supported projects.

Exhibit 27:

The Chemistry of Art for Nonscientists

Michael Henchman, Brandeis University

This course, essentially a materials science course on the fabrication, examination, conservation, and authentication of artifacts, is an effective and attractive way of teaching science to nonscientists. At present, two factors limit the course at Brandeis and its adaptation elsewhere—the lack of a suitable text and the difficulty of obtaining the necessary scientific data in a suitable form for teaching. The project has four components: (1) the development of a scientific text, limited to relevant topics treated in some depth; (2) the development of a teaching laserdisc that holds all the scientific and conservation data needed to investigate a famous and problematic artwork—The Feast of the Gods (in collaboration with the National Gallery of Art in Washington); (3) the further development of the successful laboratory component of the course, by introducing chemical microscopy for pigment and fiber characterization; and (4) the external evaluation of the educational effectiveness of the materials involved.

Exhibit 28:

A Course for the Development of 3-D Spatial Visualization Skills in Freshmen Engineering Students

Sheryl S. Marlor, Michigan Technological University

Spatial visualization is known to be a valuable and often essential skill for engineers of all disciplines. The purpose of this project is to design a three-credit course in 3-D spatial visualization and to develop a textbook and laboratory manual. The laboratory exercises will involve sketching and computer graphics and will utilize the visualization capabilities of IDEAS engineering design software. Freshmen engineering students with weak 3-D visualization skills are the target audience. Women have been found to be approximately three times less likely than men to have well-developed spatial visualization skills. Thus, it is expected that the course will increase the accessibility of engineering studies to women. The main topics to be covered are (1) 2-D patterns folding into 3-D objects; (2) building solids from coded plans; (3) sketching views of solids on square-dot and isometric-dot paper; (4) one- and two-step rotations of solids; (5) cross-sections of solids; (6) sketching solids of revolution; (7) intersection of solids; (8) introduction to IDEAS spatial visualization software; and (9) introduction to technical drawing.

Exhibit 29:

Establish Student Competence in Assessing Chemical and Physical Stressors in the Occupational Environment

Dennis K. George, Western Kentucky University

Assessing the risk incurred by a worker as a result of occupational exposure to chemical or physical agents is an extremely complex process involving the interaction of a variety of scientific disciplines. One vital aspect of risk assessment is the accurate quantification of worker exposure to the agent(s) involved. The main goal of this project is to create an industrial hygiene curriculum to teach students the basic skills involved in adequate quantification of chemical/physical stressors in the occupational environment.

Exhibit 30:

Video Resources for Instruction in Introductory Engineering Thermodynamics

Philip S. Schmidt, University of Texas at Austin

A series of 11 videotapes is being produced for use in the undergraduate instruction of introductory engineering thermodynamics. The tapes will use a combination of live-action video footage to illustrate important applications of thermodynamics and computer-generated graphics to illustrate fundamental concepts. Historical background on important people and events in the development of thermodynamics will also be presented. Topics covered will include energy; heat and work concepts; thermodynamic properties and processes in gasses, liquids, and mixtures; energy transformations and First Law analysis of closed and open systems; reversibility and irreversibility; Second Law analysis and entropy; isentropic processes and component efficiency; Carnot and thermodynamic cycle performance; and principles and applications of various power and refrigeration cycles. In addition to introductory engineering courses, the tapes are also appropriate for motivating an interest in engineering in high schools and elsewhere.

Exhibit 31: **PENS: A Simple Hypertext Notebook for World-Wide Collaboration**

PENS (Personal Electronic Notebook with Sharing) is a Macintosh-based note-taking program for team-oriented project work. It provides a simple interface for personal note taking and allows one-step sharing of these notes with project members through the World Wide Web. While minimal system administration is needed for the Web server, absolutely no knowledge of HTML or UNIX is required for students to use PENS, making it ideal for K–12 classrooms needing a basic introduction to global education.

PENS effectively merges individual notebooks into a single group notebook. Because this group notebook is published on the World Wide Web, other students and educators can browse group project notes, thus promoting cross-fertilization of project experiences.

PENS was developed under the ARPA-funded SHARE Project, a collaboration between the Stanford University Center for Design Research and the Menlo Park-based Enterprise Integration Technologies. It was developed as an experimental tool for collaborative engineering design teams and is continuously being refined through user testing in ME210, a graduate mechanical engineering design class at Stanford.

Exhibit 32: **Computer Modeling**

Wally Feurzeig, Bolt, Beranek, and, Newman

Case studies of representative examples of some of the best existing educational uses of computer modeling and visualization work will be presented. The case studies are used to focus on ways modeling technology can benefit pedagogy. The demonstrations will juxtapose several different approaches and tools to compare experiences in supporting student work with models in physics, chemistry, and biology. Exhibitors will discuss the capabilities and uses of several model development tools and applications including Explorer Science, GenScope, ScienceWorks, and Stella. Hard-copy transcripts describing these modeling environments will be available.

Exhibit 33: **Alice and National Geographic (NG) Kidsnet: A Collaborative Infrastructure Supporting Educational Use of the Internet**

Dan Barstow and Alan Feldman, Technical Education Research Center

The Technical Education Research Center (TERC), in collaboration with the states of Nebraska and Texas and other groups, is developing the first phase of software that provides a set of user-friendly tools needed to make Internet meet the needs of precollege educators. In this phase, TERC is working closely with teachers, midlevel networks, potential educational service providers, telecommunications experts, and its state partners to assess educational needs, technical resources, and software standards.

A set of the final specifications will be implemented, disseminated to participating states and other institutions, incorporated in TERC telecomputing-based projects, and evaluated. An example of a TERC telecomputing-based work is the National Geographic Society's Kidsnet—a self-sustaining, hands-on elementary school telecommunications curriculum project in use by many schools nationwide.

Exhibit 34: **Blue Skies: The Weather Underground—Application of Computer Technology to Science in Michigan Secondary Schools**

Perry Samson, University of Michigan

This presentation is based on several NSF-funded research and development (R&D) projects in the area of applying atmospheric data to science education at the middle and high school levels. The projects use software tools and curriculum materials based on up-to-the-minute, localized information from the National Center for Atmospheric Research, combined with data gathered by students. The R&D projects are working on implementation issues with a teacher enhancement project grant awarded to a large school district in Michigan. The collaboration, the materials, and the knowledge generated by the R&D work has led to the adoption of the software by the Michigan Department of Education and the use of a channel in the University of Michigan's Education Cable System.

Exhibit 35: **Common Knowledge: Pittsburgh**

Richard Wertheimer and Mario Zinga, Pittsburgh Public School District

This project has developed a set of network-based activities and provides a framework in which such activities can be implemented, tested, and evaluated throughout a local, urban-centered school system. The project has established the mechanisms with which to institutionalize the use and maintenance of network technology in the Pittsburgh public schools. The experience of the Pittsburgh public schools and the changes in its technology base will be of interest to other urban school districts.

Exhibit 36: Resources through the Eisenhower National Clearinghouse for Mathematics and Science Education

Tom Gadsden, Eisenhower National Clearinghouse

This exhibit will showcase the Eisenhower National Clearinghouse (ENC) On-Line Services along with other products and services available from ENC. The exhibit will include a display board, print materials, and computer demonstrations. Print materials will include *ENC Update* (newsletter), *ENC Focus* (topical catalogs of selected materials from the *ENC Catalog of Curriculum Resources*), and *Guidebooks to Excellence* (regional directories of federal resources for mathematics and science education improvement). Brochures and handouts will explain ENC services and how to access and use ENC Online. In addition, instructions and forms for submitting instructional materials for inclusion in the ENC collections will be provided. Computer demonstrations will permit attendees actually to try ENC on-line services including searching for instructional materials on the ENC catalog, locating resources on the Internet through the ENC gopher site, and exploring the ENC World Wide Web home page.

Exhibit 37: Cross-Cultural Systems Thinking and Dynamics Modeling using STELLA II

Diana M. Fisher, Franklin High School

The STELLA II software is a modeling language that offers high school students an opportunity to study and apply the principles of systems thinking. The software pack, using diagrams to define the system under study, allows students to consider problems in the context of their total environment. This project trains approximately 165 high school teachers, from backgrounds in math, science, and social science, in the use of the STELLA II software. The training seminars take place over three consecutive summers, targeting teachers in Portland, Oregon, and the northwestern United States. Each teacher that completes the training uses the modeling techniques in at least two classes, designs additional models, and makes a presentation to their school faculty. In addition, each trained teacher acts as a support person for others who wish to learn system dynamics. Some of the trained teachers become core team members and help provide training sessions during subsequent summers.

Exhibit 38: Investigations in Number, Data, and Space

Cornelia Tierney, Technical Education Research Center (TERC)

This exhibit highlights Investigations in Number, Data, and Space, a new mathematics curriculum for third through fifth grade students. The title reflects the view that mathematics education involves more than just arithmetic, and that students also need to work with numbers, data, space, and the mathematics of change throughout their elementary years. Each unit in the curriculum is built around several investigation models where students work with materials hands-on and explore larger mathematical problems by working with their peers. This NSF-funded curriculum is a learning tool for teachers as well as for students. While many elementary teachers are eager to change their classroom practices, they lack the materials to help them learn more about mathematical reasoning and problem-solving. In order to enable elementary teachers make the necessary shifts toward reform, TERC has developed a series of staff-development videotapes. The "Talking Mathematics" videos, which will be shown at the exhibit, demonstrate how teachers might communicate mathematical ideas to students. These tapes, and their accompanying resource package, are intended for both in-service and pre-service staff development programs.

Exhibit 39: **A Multimedia Plant Science Laboratory**

Stephen E. Scheckler and Charles David Taylor, Virginia Polytechnic Institute and State University

Ecology and evolution are major themes employed for interpreting plant structure, growth, development, reproduction, and taxonomy. We are designing laboratory software modules to be used in a newly developed plant science laboratory. A core of 15 multimedia laboratory modules has been produced. Self-help tutorials and cooperative learning exercises are also being developed. Laboratory computers are linked in a local area network so that groups of students and their teaching assistant can work on open-ended, thought-provoking exercises in a cooperative learning environment; encouraging scientific discourse and debate.

Exhibit 40: **The Age of Dinosaurs: A Science Course for Nonmajors**

Timothy Rowe, University of Texas at Austin

Multimedia software is being developed to augment classroom and laboratory materials, provide a comprehensive and up-to-date view of dinosaur history, and offer interactive training on general principles and specific information. There are separate multimedia modules on the principles of phylogenetic systematics and skeletal anatomy, flash cards of dinosaur skeletons, and a hierarchical database on the biogeography, temporal distributions, and relationships of dinosaurs.

Exhibit 41: **Faculty Internships as a Means of Systemic Change—Louisiana Collaborative for Excellence in Teacher Preparation (LaCEPT)**

David Thomas, Centenary College

LaCEPT, the NSF Collaborative for Excellence in Teacher Preparation project in Louisiana, has evolved a unique faculty internship program using activities designed to serve their SSI. Mathematics and science faculty act as full-time participants in ongoing Louisiana Systemic Initiative (LaSIP) summer inservice projects: first as learner observers; then as partial participants; and finally as full-time teaching partners. The strategy is to enhance understanding of national reform efforts in education among large numbers of mathematicians and scientists in Louisiana. The premise of the program is that enhanced understanding of national standards and trends in mathematics and science curriculum reform will lead to active involvement of faculty in the reform SMET teacher preparation.

Exhibit 42: Impact Database

George Nozicka and John Jelen, Quantum Research Corporation (QRC)

QRC is developing a database of educational impact information for NSF's Directorate for Education and Human Resources. The database will contain information on proposals and awards, principal investigators, institutions, and educational impact data for several programs in the Directorate. This exhibit will feature a demonstration of the databases for the Alliances for Minority Participation and Experimental Program to Stimulate Competitive Research programs, as well as the overall structure of the Impact Database. Additionally, the Instructional Materials Development program database will be available for examination.

Exhibit 43: Integrating Science and Mathematics for Future Teachers of the Middle Grades

Karen King, University of Maryland at College Park

This project describes the goals of the Maryland Collaborative for Teacher Preparation (MCTP) and the efforts that have been made towards attaining those goals. MCTP, now in its second year, includes integrated science and mathematics courses as well as uniquely designed field experiences and internships in its revised teacher preparation program for upper elementary and middle school education majors. Participating institutions collaborate to create courses and materials that integrate the teaching of mathematics and science. Each institution implements the program in a different way, according to its student population and needs. The poster chronicles some of the accomplishments made thus far, focusing on collaboration through technology and detailing some of the courses taught.

Exhibit 44: AskERIC: Educational Information with a Personal Touch

AskERIC—delivered through the Internet and commercial on-line services—is an exciting new information service available to teachers, parents, and students. AskERIC is a special project of the Educational Resources Information Center (ERIC), and is managed by the ERIC Clearinghouse on Information and Technology. AskERIC responds to as many as 350 questions per week and hosts approximately 15,000 "virtual" visitors to its following on-line resource collections:

- *Question and Answer (Q&A) Service.* Information specialists draw on the resources of the Internet and the ERIC system to provide answers—within 48 hours—to any question about education. (To try the Q&A service, send your questions via e-mail to askeric@ericir.syr.edu.)

- *AskERIC Virtual Library*. This is a collection of education resources such as lesson plans, print and video materials (from organizations such as CNN, PBS, and the Discovery Channel), research summaries, InfoGuides on key educational topics, frequently asked questions, and discussion groups for practicing educators and librarians.
- *National Parent Information Network (NPIN)*. NPIN, an on-line collection of materials to help parents better support their children's educational, physical, and social development, was developed in conjunction with the National Urban League, local housing authorities, and PrairieNet.
- *AskERIC Research and Development (R&D)*. The AskERIC R&D program applies emerging tools and technologies to deliver services and provide on-demand access to a full range of electronic media. Currently, the AskERIC R&D team is working on expanding the AskERIC Virtual Library to provide image, sound, and video resources; providing free Internet access to the ERIC bibliographic database using friendly, high-performance retrieval software; creating a full-text electronic collection of the documents in the ERIC database; and experimenting with new Internet products to ascertain their value for serving educators.

BRIEFING PAPERS

What are the Challenges to "Scaling Up" Reform?

Stephen P. Klein, David J. McArthur, Brian M. Stecher[1]

> *And it ought to be remembered that there is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things. Because the innovator has for enemies all those who have done well under the old conditions, and lukewarm defenders in those who may do well under the new. This coolness arises partly from fear of the opponents, who have the laws on their side, and partly from the incredulity of men, who do not readily believe in new things until they have had a long experience of them.*
>
> *Thus it happens that whenever those who are hostile have the opportunity to attack they do it like partisans, whilst the others defend lukewarmly . . .*
> Machiavelli (*The Prince*, 1513)

Background And Overview

Machiavelli was talking about politics when he penned these words, but the difficulties of introducing a new order that he described almost 500 years ago apply just as forcefully to education today. On one hand, advocates of education reform are sometimes qualified in their support; on the other hand, many opponents are openly hostile because change threatens a system they are at least familiar with, if not happy about.

In this paper, we explore some of the things that make comprehensive change in education—what we now call "bringing reforms to scale"—so challenging. The first section defines "scaling up," presents six principles that constitute some of the challenges to educational reform, and explains how these challenges arise. We draw concrete examples illustrating the principles from our work at RAND, particularly research in new assessment methods and innovative educational technology. The second section presents some ideas, motivated by those principles, for expediting the scale-up of educational reforms.

This is a "working paper." Our primary goal is to stimulate discussion on the problem of going to scale, not to propose a definitive analysis.

What is "Scaling Up"?

"Scaling up" is now a buzzword in the educational community, but what does it mean and why is it such a challenge? Many educational reforms or innovations—from large-scale systemic ones like bringing the National Information Infrastructure into schools to smaller ones like using computers to teach basic skills—fit a common mold. Researchers devise the innovation and test and refine it in a few demonstration schools. Then, they worry about implementing the innovation in a broad range of sites whose participation is voluntary. This is how most new educational technology is developed, but the model also applies to reforming evaluation, teacher training, curriculum, and other areas of educational practice.

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[1] The authors are listed in alphabetical order; they wish to thank Joyce Peterson for her editorial assistance.

Of course, many other reform initiatives do not follow this "bottom-up" model. Often, a "top-down" organization provides some global implementation plan, or at least a general rhetoric. The schools of the New American Schools Development Corporation (NASDC), for instance, are guided by several layers of organizing principles, rooted ultimately in the Goals 2000 charter. Governing bodies may also mandate changes on a large scale—replacing multiple choice evaluations with hands-on assessments, for example.

Even when guided by top-down mandates, however, the reform usually begins with a few "alpha" sites that appear to show promising results. From this perspective, the problem of scaling up is the challenge of moving from demonstration or alpha sites to a larger number of more representative sites, and eventually to all or most schools in the country. This is a substantial challenge because most sites do not enjoy the resources and publicity of the alpha schools.

Of course, scaling up is not the only way to approach reform in education. Some of the most active educational policy arenas are not focused on building better demonstration schools and then growing these small successes more broadly. Instead, they are debating changes in the operating environment of public education—how schools are managed and governed. Some of the most vital arguments concern enhancing teacher professionalism, empowering local schools and teachers to take more responsibility for their mission and success, and unleashing market forces in public education.

Five Principles of Scaling Up Educational Reform

The five principles we discuss here by no means exhaust the challenges to scaling up educational reforms; they simply comprise a set we think is interesting and, in some respects, controversial. Nor are they independent. In fact, we have tried to use the connections between them as a natural bridge from one to the next and to the recommendations that follow.

1. Effective reform requires multiple coordinated changes

Many reforms begin with a relatively simple and exciting vision of how future classrooms should look, at least in the minds of those closest to the reform. For example, our recent work in hands-on assessment (see Figure 1, top panel) offers a new way to evaluate students' complex scientific thinking. And RAND's educational technology research provides novel visualization and tools that enable students to learn higher-order problem-solving skills in geography and social studies (see Figure 2, top panel). Both of these reforms substantially change educational processes and goals. With new assessment instruments, for instance, evaluation is a contextualized and interactive process, like scientific practice itself, rather than being reduced to a selection from multiple choices. Pilot studies have shown that our educational technologies also qualitatively transform students' learning outcomes, not just quantitatively improve them.

Scenario:

In new hands-on tasks ask students to perform scientific investigations, observe and record results, draw conclusions, and apply the principles they uncover to related situations. For example, one task shell assesses the ability to draw inferences in the domain of physics. Students perform experiments involving a pendulum or a set of levers, determine which variables (length, weight, position, etc.) correlate with observable outcomes, draw conclusions, and then apply these conclusions to new situations that they cannot test physically. Another shell teaches students about two-way classifications and then asks them to construct a valid two-way classification of their own devising using a set of animals or a set of materials. At the end, they are given an additional animal or material to classify using their system; they must either assign the object to the proper cell or make change to the system to accommodate it.

Required changes for scale-up:

material development and storage—assessment kits are large, requiring substantial storage space
initial teacher training—teachers must learn new and more complex administration procedures
scoring infrastructure—teachers must be trained to understand and apply new types of scoring guides
continued mentoring and monitoring—teachers need coaching to maintain non-routine testing skills
support material—textbooks and related documents are required to inform staff and parents about new assessments
classroom schedules—scheduling changes are needed to accommodate longer testing times

Figure 1. Assessing science knowledge using hands-on instruments.

But largely because these reforms can transform education, rather than incrementally enhance educational "productivity," scaling them up effectively demands that extensive changes be made to the classroom (see Figures 1 and 2, bottom panels). These changes are often much less obvious than the "core" innovation to reformers. For example, we have considerable experience in developing new educational software, but we have to tackle the task of integrating these programs into curriculum development and classroom design. Yet, to scale up innovations such as ours, these diverse, additional reforms must be carefully coordinated with technology development.

Scenario:

Students working in pairs use the ARC/INFO geographical information system to conduct self-directed inquiries with the ARCUSA database, a county-level data set for the USA that includes dozens of demographic variables. Student inquiries usually revolve around finding interesting relationships among two or more variables developing hypotheses to account for the data, and finally formulating explanations and defending hypotheses. Students rely on interactive maps (colored like *USA Today* temperature maps) and additional computer tools (like bar charts and scatter plots) to conduct their inquiries. For example, a pair might generate maps to discover that teen pregnancy rates are high in the southeast and low in the northeast. They could then formulate hypotheses to explain this pattern —for instance, attempting to relate high pregnancy rates to low education rates and low income by looking for "reverse" patterns in the maps for these variables.

Required changes for scale-up:

courses—changed from primarily lecture to project-based learning
curriculum—combine geography, social sciences, as well as statistics in a single course
classroom—students work in groups; classes last 2 hours, not 50 minutes
teacher roles—teachers act primarily as mentors, not "sages on the stage"
evaluation—examinations are performance-based not test-based

Figure 2. Teaching geography and social studies using ARC/INFO.

Even more challenging, these additional changes go well beyond the need for new materials, storage, and research. Teachers in the classroom will have to master more than just the core innovation itself: They will need to teach new content, in new ways, using novel tools. Extensive relearning requires a training infrastructure. For example, accepted wisdom would dictate that teachers attend workshops to learn how to administer hands-on science assessments. But beyond this initial training, they need continued support and mentoring: Teachers will use these new instruments only a few times each year. At least for the first few years—until this reform becomes routine—they will need timely refresher courses/practice from mentors who are credible experts in the field.

Although the core of a reform is often just the beginning of numerous changes, not all educational innovations are so demanding. For instance, we fielded an intelligent tutoring system for algebra that did not require fundamental changes in what teachers taught: It simply replaced them as a drill-and-practice coaches, without fundamentally changing what they teach or how they teach it. The trouble, unfortunately, is that substantial changes, and the implementation challenges they imply, increasingly dominate the core innovation as it departs from existing classroom practice. In other words, as an innovation looks more like a true reform rather than an incremental modification, the more it will require multiple, often unanticipated, classroom changes.

II. Effective reform requires the will and agreement of multiple actors inside and outside the classroom.

Although multiple supporting changes are often necessary conditions for scaling up reform, they are sometimes not sufficient. In many cases, successful reform also depends as much on a community's will to change as it does on the diverse knowledge required to implement a reform. The failure of the Bensenville NASDC school, for example (see Figure 3) illustrates several barriers outside the classroom itself.

Bensenville, Illinois, was awarded $1.25 million by NASDC in 1992 to implement its vision of a "break the mold" school. The Bensenville project was unique among the NASDC schools because it conceived of learning as a lifelong process based in the community, not just the schools. Hearkening back to Dewey's progressive movement, it called for involving students in meaningful real-life situations, bridging the gap between home and school, and education that adapted to the needs and abilities of individual students.

The Bensenville project lasted less than two years and never completed its initial implementation. Among the main reasons for this failure were: (i) successful governance of the Bensenville school required merging school districts but they were unable or unwilling to cooperate; (ii) the project required substantial new revenue in the form of taxes, but the community did not want these increases; and (iii) the design called for individuals in the community with expertise in different areas to act as instructors, but teachers objected to uncertified mentors.

Figure 3. The failure of the Bensenville NASDC school.

Among other things, the Bensenville example highlights how different reform in public education is from, say, corporate reform. Businesses that implement innovations on a broad scale can, and often do, flounder because they do not plan for the multiple changes innovation requires in the workplace. But, within broad constraints, they can impose plans on their business without answering to diverse, powerful groups of external stakeholders—not so with public education. Even a highly promising reform can be crippled from the outset by a community that does not want to raise local tax rates, a parents' group that does not want children outside school during class hours, or a school board that objects to some feature of the reform.

In short, reform in education has a political dimension that—like the many substantial changes we mentioned—must be addressed before an innovation is implemented. And the greater the reform, the more likely political factors will play a key role. Fortunately, in many cases the reform can move forward with a simple change in the will of a single stakeholder group. For example, one vote from a teachers' union could extend the school year or lengthen the school day. But changing such opinions may be more costly than developing the curricula, teacher training, and classroom organizations that are needed to scale up an educational reform.

III. Economies of scale operate only weakly in educational reform.

The substantive and political challenges to scaling up might be eased if educational costs declined at scale. Economies of scale do indeed work well for the *material* components of reform: The kits for hands-on science assessment that are expensive to provide for a few classrooms are relatively cheap if mass-produced. More dramatically, hardware and software costs for educational technology should plummet if reforms extend beyond a few classrooms. Computer companies might even see education as a viable market.

However, economies of scale will not apply to all facets of reform, including many of the more hidden substantive and political aspects just mentioned. For example, the infrastructure—trainers, quality control mechanisms, and monitors—needed to support teachers who conduct hands-on assessments increase with scaleup. Supervision to manage assessment fidelity comes in layers, and increases in program size imply more layers. Unlikely events that can be ignored in demonstration sites become highly probable as we scale up reforms. One "school of tomorrow" can rely on nearby researchers to fix the occasional broken laptop computer; with a dozen such schools, a district may need to hire computer wizards.

A second economic principle also helps explain possible diseconomies of scale: the law of diminishing returns. The first schools to embrace a reform are often typical "early adopters" of innovation. As such, they can expect to pay exceptionally high material costs; but their people-related costs are likely to be comparatively low. These schools usually include teachers, administrators, even students, who already have the will to change and much of the knowledge to implement the reforms effectively; and they may be part of a community that poses few political threats to reform. By contrast, schools that adopt a reform later are less likely to have the knowledge and motivation to see the long implementation process through to successful completion. To some extent, additional resources—in the form of professional development of teachers, for example—may bring more schools into the fold. But, at some threshold, the cost of reforming each new school may become prohibitive, and there the scaleup of reform effectively halts.

IV. Scaling up is local, and is more adaptation than replication of a reform model

Economies of scale might work better if education were more like manufacturing. Factories enjoy economies of scale because after the initial investment to design a new cookie-cutter, the marginal cost of producing cookies quickly drops to profitable levels. Turning the analogy around, the limited economies of scale in education simply reflect the fact that reformed schools are not commodities—in most cases we cannot expect to scale up a reform by replicating a demonstration school that personifies the reform. Rather, each school is likely to adapt the reform to its own needs. In short, all scaling up is local even when reforms are supported by national mandates, informed by broad standards, and implemented in demonstration sites.

In fact, research has shown that implementation is more effective when reforms are adapted at the local site (Berman and McLaughlin, 1978). Understanding this principle, educators have developed reform strategies that incorporate local adaptation. Sometimes, a single reform model is crafted with tailoring options explicitly built into the design. For example, in a computer-based course for high school statistics, which we developed, teachers were able to pick and choose modules to suit the background of their students, the interests of the class, and in some cases the limited expertise of the teacher. At a different level, whole-school reform may permit adaptation by offering a choice of models. Eleven (now nine) distinct model schools were developed in Phase I of the NASDC initiative; in Phase II these models have spread to around 150 sites; and Phase III promises thousands of versions of these different reform models. Here, then, scaling up a reform not only gives schools freedom to adapt a vision rather than copy it, but also gives them a choice among several competing visions.

But what constitutes a reasonable local adaptation of a reform and how can we tell whether a version adapts a reform or violates it? This concern is far from trivial because in many cases successful scaleup of a reform tolerates very little variation. For example, to bring hands-on science assessments to scale, it is important that every teacher administer measures and evaluate responses in a uniform way. Such standardization is critical if the scores are used—as reformers hope—to compare students, schools, and districts.

Other reforms permit more adaptation, but then it becomes tougher to make judgments about how much adaptation is too much. Initiatives like NASDC, for example, include general reform principles and standards, as well as specific demonstration schools, so presumably one could judge the fidelity of a site's implementation with reference to these underlying concepts. Yet, judging whether a site is consistent enough with general reform principles is challenging even for reform experts.

V. Since reform targets may change, the process of reform is more important than the end-state.

If scaling up is local adaptation, then a reform might be successful even when all (or most) schools do not conform to a single fixed vision. Not only will an innovation change with local context, but also the speed of reform will vary from site to site as a function of the resources, knowledge, and interests of local communities. Unfortunately, the longer schools take to implement a reform, the more likely that they will find themselves chasing a moving target.

Of course, the target of reform may vary because each school adapts the reform vision to suit its needs, or because, like the NASDC sites, it picks one target rather than another. But the principles underpinning the entire innovation itself may change, forcing each site that has committed to the reform to reconsider its position. On a relatively small scale, organizations that set standards for a field (e.g., NCTM) revise these standards from time to time. But this generally amounts to fine-tuning an existing reform. A much more dramatic situation may arise if a completely new cycle of reform begins, superseding the current one well before it has been implemented in a significant number of schools. In some cases, the reform cycle can even be so short that it actually discourages any implementation of the reform; this kind of situation gives rise to some of the most creative adaptations of all. Rapid cycles of reform also can stifle initiative. RAND research (Stecher et al., 1994) has described the frustration of state vocational education administrators who are so suspicious of ever-changing federal policy that they delay implementation of reforms because they expect that "this too shall pass."

Several cynical interpretations of this dilemma arise rather naturally: that reformers move on to more exciting new ideas before schools can realize the old ones, that the old ones were not worth implementing in the first place, or that political forces overthrow good ideas before they get a fair test. All this sounds quite hopeless for reform, but there may be a positive way to view this chase. Perhaps the most important aspect of reform is not the specific goal, or final product of reform, but the process of reform itself—the commitment on the part of individual schools and the entire educational sector to continually improve public education.

Indeed this is just what advocates of Total Quality Management (TQM) in education have argued. From the TQM perspective, schools should not necessarily abandon specific reform goals. However, if these goals require a long time to achieve, or if reform visions shift when chased, it might be better to concentrate less on the end-state of reform than on the means that shape each step towards that end. For instance, vocational education administrators are often frustrated by ever-changing federal rules. They might be more motivated to embrace reforms under policies that support the day-to-day processes of enhancing the quality of education: cultivating continuous improvement, adhering to a constant purpose, nurturing a philosophy of high quality and customer-driven service, decentralizing decision-making, and sharing understanding in the school and community culture. From this perspective, the content and goal of the reform is less important than the incentives and processes.

Expediting Scale Up

The five principles above should not be a source of frustration or pessimism. Granted, they identify problems associated with scaling up, but they also suggest design features and implementation strategies that can be used to increase the chances of success. Research on educational reform suggests procedures for facilitating change in schools, and some are particularly relevant to the problems of scaling up:

- **Anticipate unexpected events and problems and include mechanisms to address them**. Even when the elements of a reform are well tested for use, developers seldom adequately address the question, "What can go wrong?" In our science performance assessment work, where fidelity is crucial, unanticipated problems were legion: Rocks that were supposed to float did not, vegetable samples rotted, bottles leaked, packages did not contain identical contents, etc. As a result, we learned how to design materials to make them more transportable, more standardized, and easier to implement (such as by largely eliminating teacher demonstrations of apparatus). Furthermore, as the scale increases, the occurrence of low probability events also increases. It is more difficult to plan ahead for a very unusual occurrence—misprinted materials, lost shipments, casualty damage, words or phrases that offend various groups, etc.—but it is helpful to realize at the outset that "if you can imagine it, it will probably happen at least once" and make preparations to respond. Design in extra troubleshooting and response capacity.

- **Conduct adequate, independent field testing of the program—exactly as it will be implemented**. One way to avoid unexpected problems is to pilot test and revise the innovation repeatedly before wider implementation. Developers naturally want to see their program widely distributed as soon as they work out the initial bugs. However, our experience suggests that multiple rounds of pilot testing and revision are essential to identify and remedy operational problems that will interfere with scaling up, and could possibly give the reform a bad name. Typically, initial prototype development is done in close consultation with a small number of schools or classrooms. Such "alpha" testing has users intimately involved in development. This level of prototype development must be supplemented with "beta" testing: New users not familiar with the evolution of the product try to implement it under conditions that are likely to prevail in large scale distribution. This true field testing reveals potential pitfalls that will never be apparent to the "alpha" testers. In test development, we had to go through multiple rounds of beta testing and revision before we had materials that could truly stand on their own.

- **Package the reform materials so that little "assembly" is required**. If teachers must to do extra preparation before using materials or equipment, they are less likely to use the materials. For example, teachers were much happier to administer hands-on science tests when the test kits were prepackaged for each student than when the materials were shipped in classroom sets requiring sorting and repackaging for each student. The same principle holds for other aspects of the reform, including installing and preparing software, assembling notebooks or workbooks, searching out supplemental texts, and more. Scaling up will be easier if the things teachers need are readily available in the form teachers will need them.

- **Emphasize goals and objectives that teachers, administrators, and the professional education community see as credible and worthwhile**. People will be more enthusiastic about and committed to reforms that address continuing, new, or important problems than reforms that are tangential or rely on extrinsic (top-down) motivation. Similarly, reforms that are supported by appropriate research evidence and endorsements will fare batter than reforms without that backing.

- **Build on teachers' existing knowledge and skills**. Teachers bring knowledge and skills to the reform effort. It may be more productive to emphasize use of existing talents rather than the need to master new skills for overcoming perceived deficiencies. This is a more positive way to approach reforms that require significant changes in the knowledge base of teachers, either new content knowledge (curriculum reform) or new pedagogical knowledge (instructional reform).

- **Provide the necessary infrastructure to support scaleup**. This includes elements, such as start-up training, that are commonly incorporated into dissemination models, as well as mechanisms for ongoing support, monitoring, and troubleshooting. Scale-up assistance and support must be easily available, timely from the user's perspective, and accurate. For example, a technology-based reform may require assistance from "local wizards" or "gurus" who are immediately accessible and can help teachers resolve common problems. The person providing the assistance must have credibility for users. The latter condition can usually be met by having a teacher serve in this role.

- **Accurately estimate the resources necessary to support scaling up**. It is easy to underestimate the costs associated with scaling up and to launch these efforts with inadequate budgets. Some reforms, such as technology-based programs, laboratory science, or other hands-on curricula, require resources that are expensive or not readily available. This must be anticipated in budgeting. Designers must be sure to provide resources to support a reasonable scale-up infrastructure of the type discussed above. Inadequate support can frustrate users and ultimately lead them to abandon the effort. For example, users of at least one early computerized instructional program complained, "It was a fine program, but the system crashed a lot in the first year, and when we called the hotline for support, all we ever got was a busy signal." It also is important to ensure that support is available for an adequate length of time. As Bimber (1993) notes, "Those planning and funding a reform often must be prepared to persist for years before seeing expected changes come to fruition."

- **In the design and the implementation model, include provisions for involving the community and institutional constituents who will be affected by the reform**. In some cases involvement may mean participation in key decisions about adoption and adaptation. Participation by parents and the community at large may prevent contentious challenges that can undermine a reform. Sharing information about the reform may improve the reception. For example, many school technology projects have been embraced by parents who understood the purposes of the project and were given an opportunity to learn about computers themselves through after-school classes and demonstrations. In short, scaling up will work more smoothly if the adoption and implementation process includes all the constituencies likely to be affected by the reform.

- **Provide incentives to participate in the reform**. Incentives need not be in the form of financial remuneration; personal satisfaction and institutional recognition are powerful motivators as well. Professional incentives such as leadership and promotional opportunities can be effective tools for change (Bimber, 1993). Other types of incentives might include salary point credit for training, relaxation of administrative rules, greater professional responsibility, parties and social events, released time for other activities, and preferential access to scarce school resources such as field trips, equipment, laboratories, and more.

- **Avoid reforms that depend on "geniuses."** Some programs rely heavily on the skills, knowledge, or personality of an especially wonderful and effective teacher, program supervisor, or motivational leader. Such unusual features will be difficult or impossible to replicate.

- **Engage participants intellectually in the process of change rather than merely asking them to follow procedures and routines**. It is difficult to overestimate the importance of "engagement" as a factor in change. Staff who find the concepts interesting and the results exciting on a personal level will be more likely to invest time and energy in changing their behaviors than those who do not.

- **Help schools capture the time necessary for change**. Time is one of the greatest obstacles to change. As Purnell and Hill (1992) noted,

> When schools, districts, and foundations plan the strategies and tactics of reform, the issue of time becomes an important consideration. . . . Time is a finite resource. Simply adding school reform to the list of "things to do" trivializes the process and reduces the time available for every item on the list. . . . Schools need to find some source that will provide the resources to create enough slack for teachers to identify, design, and begin implementing changes while the school continues to function. (pp. v-vi)

Most educators recognize that teachers will need time to attend training events, but many forget that teachers will also need time for experimentation, follow-up assistance, and practice. In addition, they will need time to acquire the underlying substantive knowledge and pedagogical skills required to implement the reform.

Summing Up

This paper discussed several principles and factors that affect the scaling up process and make it difficult to scale up educational innovations and reforms. The greater the change required (in what teachers need to know, in the ways that schools are managed and operated, in how students spend their time, etc.), the harder it will be to achieve broad-based change. All the stakeholders—especially those who have to pay for and implement the change—have to be convinced that, on balance, the proposed reform is appropriate and beneficial in their particular circumstance. All too often, however, there is insufficient long-range planning and infrastructure development to ensure the reform's effectiveness and utility. Moreover, widely spread innovations almost invariably encounter problems that undercut their reputation and acceptance. In short, the barriers to scaling up educational innovations are formidable. Nevertheless, these barriers can be overcome, in part, through better understanding of the factors involved. We hope this paper will further stimulate the discussions that are necessary to achieve that understanding.

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Stephen P. Klein, David J. McArthur, and Brian M. Stecher, work for the RAND Corporation, Santa Monica, California.

Workforce Issues in Spreading Excellence in Science and Mathematics

Ray Marshall

The theme of this conference is very appropriate to the related challenges we face in the American economy and in reforming our education system to make it possible to maintain and improve our incomes—something most Americans have not been able to do since 1970. Spreading excellence in science and mathematics also is a particularly important challenge in education. Since these are very basic subjects that ordinarily are not handled very well in our schools, any satisfactory school reform effort must give high priority to excellence in science and mathematics. We provide excellence in these subjects in some places for a *few* of our students, and some projects give insight into how to teach these subjects to *all* students, but a high-performance economy requires that we provide better opportunities in these subjects for every student, not just a small percentage of those who intend to major in science, math, or engineering at the college level. Our best math and science students probably would reach a higher level of excellence if all students were required to achieve a basic competence in these subjects. In the early part of this century the United States did pretty well in educating a small elite in these subjects and importing scientists and mathematicians from abroad. We can still import high-level scientists and mathematicians, but that does not solve the problem of providing education in these subjects for all students. Indeed, the availability of foreign scientists and mathematicians could actually distract from our need to embed science and mathematics in the education of all students.

This paper focuses on a particularly troublesome aspect of American education system: the education provided to those students who do not plan to pursue baccalaureate degrees immediately after high school. We devote much attention and many resources to those students who plan to attend college, but do very little for the majority of students who do not. A good guiding hypothesis is that America's future depends heavily on providing educational excellence, especially in math and science, for workers who do not enter college immediately after high school. It seems to me that the evidence supports the following propositions:

(1) The low math and science achievement problems of American students are due to weaknesses in most of our learning systems, especially for students who do not plan to attend college immediately after high school. These weaknesses are deeply rooted in U.S. economic and social history.

(2) From an economic perspective, our basic problem lies in the success of an organization of work that allowed most workers to earn decent incomes without high levels of formal education. Indeed, the success of that system caused most Americans to value schooling as a social institution and provider of basic literacy, but not for more abstract subjects like science and math. The system created an aversion to "theoretical" or abstract learning that is so critical to success in today's global, highly competitive, knowledge-intensive world. The mass production system caused a rapid increase in our standard of living because of easy improvements in productivity through economies of scale (which, in turn, was made possible by a large and prosperous internal market) and an abundance of natural resources. In this organization of work only a few managerial, professional, and technical people needed sophisticated math and science skills; most workers who were willing to accept the necessary disciplinary conditions and work hard needed only basic literacy and numeracy to earn incomes that were high relative to the alternatives in rural areas or other countries.

(3) However, the United States and most advanced countries have undergone profound changes that require a very different organization of work and much higher intellectual skills for all workers who wish to maintain or improve their earnings. The root cause of these structural changes are science and technology, which have done a number of things to increase the importance of math, science, and other intellectual skills. First, science and technology have greatly reduced the natural resource content of most products and greatly increased the intellectual content (i.e., ideas, skills, and knowledge). Indeed, technological progress is essentially the substitution of ideas, skills, and knowledge for physical labor and natural resources. For example, agricultural economists working in the tradition of Nobel laureate Theodore Schultz have found that American agricultural output has greatly increased since the 1920s, despite the use of less labor and physical resources. Similarly, Peter Drucker tells us that the seminal product of the 1920s, the automobile, was 60 percent energy and raw material and 40 percent ideas, skills and knowledge; by contrast, the seminal product of the 1990s is the computer chip, which is 98 percent ideas, skills and knowledge and 2 percent energy and raw material (mainly sand or silicon). Clearly, therefore, science and technology have caused natural resources to become progressively less important and ideas, skills, and knowledge to be progressively more important.

Science and technology also have dramatically changed the optimal organization of work. Most important, advances in communications and transportation have greatly intensified international competition. Earlier in this century economic activity was mainly national and organized on the basis of large oligopolistic firms which prospered from economics of scale and constant improvements in, and dissemination of, mass produced, standardized technologies. By making more information available on a global basis and to participants within the enterprise, science and technology have caused competition to undermine regulated or oligopolistic markets. Information and transportation technologies stimulate competition and transform the work organizations required for economic success. In particular, transportation and communications technologies break local monopolies by giving consumers and producers much more knowledge about, and choices of, global technology, goods, and services markets. Oligopolies and "natural" monopolies (in communications, transportation, and utilities) therefore become anachronisms.

Global competition presents people everywhere with stark economic choices: competition can be either on the basis of working harder (i.e., using more physical labor and natural resources) or working smarter (i.e., improving productivity and quality by using more ideas, skills, and knowledge). In a global economy, the working harder option is inherently self-limiting, implies competing with low-wage countries, and results in lower real wages for most workers and a widening income distribution between those who work mainly through the use of ideas, skills, and knowledge and those who mainly work harder. This is exactly what has been happening in the industrialized countries, but more so in the United States than any other technologically advanced economy. The only American workers who are better off now in real terms than in the early 1970s are workers with baccalaureate or higher degrees. The education/income gap has widened greatly. In the 1960s, college graduates earned 20–30 percent more than high school graduates; today, they earn 70–80 percent more.

(4) A major factor accounting for these trends is a change in the optimal organization of work, which in turn requires more intellectual skills for those who wish to improve productivity and quality. These high-performance work organizations eliminate many layers of administration and decentralize work. They also develop and use leading-edge technology. Standardized technologies that can be imported to the enterprise become a commodity that will provide little competitive advantage, since competitors can acquire the same technology. Economic advantage therefore is derived mainly from the organization of work and workforce skills. Leading-edge technology will require more ideas, skills, and knowledge to be added to technology in the enterprise in order to adapt to the realities of each work place. Standard-

ized technology with increasingly high intellectual content is crucial for survival in many industries, but will not necessarily provide a competitive advantage.

By contrast, leading-edge technology, which results from workers "giving wisdom" to the machines, can provide a competitive advantage. New capital investment makes it possible for enterprises to import ideas, skills, and knowledge embedded in machines. But the people within an organization must adapt the new imported technology to the realities of each workplace. The physical capital in machines is thus much less important than the ideas, skills, and knowledge embedded in the machines (or the ideas, skills, and knowledge added in the workplace).

(5) Clearly, high-performance work implies much steeper earning curves and less constrained productivity growth and therefore much more room to improve living standards. Since high-performance workers have considerable discretion, they are less easily monitored and therefore are guided more effectively by clear goals and objectives and positive incentives than by rules, regulations, and supervisors. There is, moreover, growing international consensus about the kinds of skills needed to function effectively in high-performance work. All of these skills imply much higher emphasis on math and science. One of the most important of these skills is the ability to impose order on the flood of often chaotic information made available by modern technology. High-performance work is more likely to be group work which requires interpersonal and communications skills. High-performance work requires self-management and problem-solving skills strengthened by an understanding of scientific and experimental methods. Since high-performance work is less likely to be standardized or routine, it requires workers to have diagnostic skills as well as an ability to deal with ambiguity and be creative. A critical skill in such workplaces is the ability to learn by using abstractions. Indeed, the most distinguishing characteristic of a high-performance work organization is that it is likely to be an efficient learning system, with much higher priority to the education and training of frontline workers. Standardized mass production systems, by contrast, concentrate almost all of their education and training resources on managerial and technical training, emphasize fragmented routine work for most frontline employees, and are very inefficient learning systems.

(6) The United States has very serious weaknesses in producing the skills required for high-performance work. While we have a few high-quality technical training activities, our only world-class learning systems are upper division work in colleges and universities and our graduate research institutions. The first two years of most colleges and universities in the United States require what would be high school-level work in Japan or Germany. And only the very small proportion of secondary school students destined for college and post-graduate work acquire high-performance intellectual skills.

Our greatest educational deficiencies are in elementary and secondary schools, preparing non-college bound students for work, and work-based training systems. It should be noted, however, that many of our education problems start in families, the earliest and most basic learning systems. We have a much larger proportion of children in poverty than Japan or any West European country. And with some remarkable exceptions, poor families are not good learning systems. But our problems are not restricted to poor families. Most families experience stress because of economic insecurity due to structural changes in families and the economy.

(7) What can we do about these problems? Space will only permit an outline, but my list would be as follows:

- Give much higher priority to the problems of families with children, especially the families of poor children.

- Develop standards-driven systems for elementary and secondary schools with high math and science content. If we had high standards for graduation from high school, we would have to do less remedial work in college and could start workplace and pre-work training at much higher levels. Standards help motivate students and teachers, provide a means to evaluate performance, and a way to achieve linkages and systemic efficiency in learning systems. Under present conditions, it makes little difference how well students who do not plan to pursue baccalaureate degrees perform in secondary schools. Standards would change this and provide a broader understanding of what graduates know and are able to do. Assessments should be on the basis of performance, not just written tests. Fortunately, good math and science standards have already been developed; these can be constantly improved.

- Involve employers much more in developing education standards, improving support for schools, and providing jobs for graduates who meet these standards. American companies take little responsibility for improving school performance, either by hiring recent graduates or by providing constructive feedback on school performance. Companies consequently must either continue to use less productive forms of work organization or provide expensive remedial work better done in cooperation with schools. Closer cooperation between industry and education would benefit all students, not just those who plan to go to work right out of high school. Learning math and science could be improved, for example, if students learned while applying and observing the uses of these subjects in the workplace. Most students need to know more about career options than they do, and at an earlier age. Some recent activities like the academies related to finance, health care, electronics or other industries provide good examples. These academies are small schools within schools and meet most of the cognitive science tests of good learning situations. Few traditional schools could meet these tests. Indeed, spreading excellence in math and science requires much more attention to the lessons of cognitive science in all instructional programs.

- Relative to their principal competitors in other countries, most American employers not only pay very little attention to elementary and secondary schools, but also do very little to provide high-performance skills to their frontline workers. United States employers resist training requirements like those imposed by law or custom in other countries, even though they understand the need for training and know that they underinvest in skill development for frontline workers. Political leaders therefore should redouble their efforts to build political support among businesses for incentives to induce more and better on-the-job learning. One of the most basic ways to achieve this would be to create strong disincentives for low-wage competition and strong incentives for companies to compete through high performance. A major incentive for high performance would be the ready availability of students with high-performance skills, but much more would have to be done, including more stable and transparent economic policies, adequate social safety nets, and improved protections for employee participation in workplace decisions.

(8) How do we spread math and science excellence in our learning systems? Having math and science standards *all* students are expected to meet is a necessary precondition for the spread of excellence in these subjects. Second, schools themselves must be high-performance learning systems with world-class standards for student achievement, and highly professional teachers and administrators who take responsibility for student learning and who are rewarded for meeting high standards for all students, especially minorities and low-income students who are not well served by traditional schools. It is particularly important for schools to be restructured to reflect the lessons of cognitive science. There also should be disincentives to prevent dropouts. One disincentive would be to have schools lose money when schools drop out. Schools must also have incentives to incorporate leading-edge learning technology into their

learning process. However, schools should have discretion about how to meet standards. Unfortunately, while there are many promising experiments and beginnings, most of our schools are still geared to the needs of a natural resource-oriented mass production system, not the requirements of a knowledge-intensive, highly competitive global economy.

The major challenge this country faces is not to understand what is required to achieve excellence in *particular* schools, but how to achieve high-performance school *systems*. A promising method is to learn from the techniques embodied in the 1994 Goals 2000 and School-to-Work Opportunities acts. These acts contain mechanisms designed to encourage systemic change. Those of us concerned about math and science education should work to ensure that standards for these subjects are included in change processes. In the School-to-Work Opportunities Act, the federal government did not mandate processes for the states, but provided incentives for state and local officials to work voluntarily within broad federal guidelines to improve performance and left it to the states to experiment with ways to achieve this objective. States were invited to apply for grants and waivers of federal regulations. In the first round, priority went to states that committed to systemic change based on standards. This approach could lead to experimentation and steady improvement in our learning system by the end of the century.

As the nation faces the future, NSF has focused its efforts on broad and deep reform. "Systemic reform," named such because it is designed to change the basic system and not a particular component or "tool," promises to remake curriculum, instruction, assessment, staff development, and teacher preparation, as well as the relationships among educational institutions, the world of work, and the society in which we all live. The three major programs focused on this effort are: Statewide Systemic Initiatives, Urban Systemic Initiatives, and Rural Systemic Initiatives. These programs emphasize encouraging states, major cities, and rural areas across the nation to initiate comprehensive efforts to make lasting improvements in SMET education systems via new paradigms.

- The Statewide Systemic Initiatives (SSI) Program supports 24 states and the Commonwealth of Puerto Rico in establishing comprehensive changes in SMET education through development and alignment of new standards, partnerships, policies, and practices. Although SSI is relatively new, it is having a profound impact on the SMET education community nationwide: collaboration between elementary and secondary education and higher education is becoming commonplace; business people and educators are working together; curriculum, instruction, assessment, and staff development are becoming increasingly aligned; and policymakers are helping to reduce policy barriers and create enabling policy and legislation. In addition, many states that did not receive SSI funding are making the changes that they had proposed to NSF and are learning from SSI-funded states. Within NSF, systemic reform is being used more often as a program approach. Other agencies are emulating NSF's SSI program, with systemic reform being applied in nonscience and mathematics disciplines.

- The Urban Systemic Initiative (USI) Program targets the 25 U.S. cities with the largest numbers of school-age children living in poverty. USI challenges urban school districts to reform SMET education systems to provide adequate grounding in these areas for all students. USI brings together two major forces in education, the need for systemic change in SMET education at the elementary and secondary levels and the need for enhanced national productivity for groups that traditionally have been underserved by our national education system. All 25 cities have received planning awards, and nine have received implementation awards.

- The Rural Systemic Initiative (RSI) Program completes the trilogy of education systemic reform efforts by focusing on rural areas that are characterized by high and persistent levels of economic poverty. It is hoped that the projects will be co-funded among several federal agencies, particularly NSF

> and the U.S. Department of Education. NSF has made four development awards to support advanced planning in clusters of rural counties with a history of cooperation and significant cultural and economic commonalities. Four awards to support initial planning have also been made.

Likewise, it is very important for educators, especially in math and science, to help political, business, and community leaders understand the importance of, and give higher priority to, excellence in education for all students. This means consciously articulating the importance of mathematics and science in terms that are comprehensible and credible to business and political leaders, as well as the general public.

Math and science are important, not only for their substantive content, but also for the increasingly important habits of mind they inculcate. Unfortunately, one of these mental habits is too often fear. This is based on the myth that learning—especially of math and science—is due mainly to innate ability. By contrast, the lessons of cognitive science, as well as alternative and restructured school experiences, suggest that learning these subjects is due mainly to hard work, motivation, and supportive learning systems. If our math and science education processes reflect these lessons, they will do much to combat myths about learning and create better conditions for expanding excellence in learning.

Ray Marshall, Professor, Lyndon Baines Johnson School of Public Affairs, The University of Texas, Austin, Texas. Professor Marshall served as Secretary of Labor in the Carter Administration.

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Tech Prep: A Business Perspective

Carver C. Gayton

Although I write this paper as a Boeing company executive, I feel comfortable stating that the challenges Boeing faces as a global industry can be generalized to other large, high-tech manufacturing companies throughout the nation. If The Boeing Company is to remain globally competitive and maintain its position as the number one commercial airplane company in the world and the number one exporter in the United States, the company must look at more and better ways to cut costs and, at the same time, improve our processes, products, and services.

In the past, Boeing has confronted several major cost challenges. Among them, the European government subsidies for Airbus Industries, a European commercial airplane manufacturer, in the face of no U.S. government subsidies for Boeing products have made the playing field in the commercial airplane business between Europe and America uneven. While the U.S. government is attempting to resolve this issue with Airbus, Boeing must compete despite the obvious cost advantage Airbus has in manufacturing its product.

In addition, the costs related to environmental regulations, including record-keeping, training, and compliance costs have increased 115 percent over the past two years. This point is made not because Boeing is averse to environmental regulations, quite the contrary. This is merely another example of an expense that must be factored into the price of Boeing's airplanes. Other structural costs have also increased; health costs for our employees increased 55 percent between 1988 and 1991, and there are no indications, at least in the near term, that such costs will not rise further.

We face other problems as well. Basic skills of new employees, particularly those coming directly from high school, are less than we need. For example, a comparison of recent math and science test scores of students at the ninth grade level in industrialized nations places America's students near the bottom. The skill level of a significant segment of the nation's future workforce should be improved, and, at the same time, the kinds of needs workers have are changing.

At least 70 percent of new entrants into the workforce between the mid 1980s and the early 21st century will be primarily women, minorities, and immigrants. Two questions emerge from this statistic: (1) Are nontraditional employees prepared to meet the higher-skill standards of many of today's high-tech industries? and (2) Are managers prepared to take advantage of the value that can be added to products and services from the diverse perspectives of these new employees? Both questions provide strong challenges to educational institutions and industry.

Because 70 percent of high school students are going directly to work or community colleges, rather than four-year institutions, and up to 50 percent of those who do enroll in bachelor degree programs may never graduate, more energy must be directed toward such students—Dale Parnell's neglected majority—to enable them to transition more easily into the workplace. Also, because the rate of poverty for children is three times greater in the United States than other major industrialized nations, the U.S. cannot compete globally with countries like Japan and

Germany, which generally do not have to expend resources to deal with poor, undereducated, underskilled citizens.

Internal Activities with The Boeing Company

At The Boeing Company, we are not passively bemoaning the fact that the previously stated problems are upon us. There is a sense of urgency, however, that is permeating the entire organization. If we expect to remain the number one commercial airplane company in the world 20 years from now, we must quickly change the way we operate. To this end, we are promoting programs that focus on:

- working with teams;
- hiring and developing employees who can adapt to rapidly changing technology;
- developing managers as coaches and leaders; and
- operating within a continuous quality improvement environment.

Team Building

From a practical point of view, working in isolated, functional areas at the outset of projects creates an atmosphere of turf building, intrigue, distrust, and ultimately more costly products and services. The new 777 commercial aircraft under development by Boeing is being designed in teams of customers, engineers, finance workers, and technicians. This approach has cut engineering design costs in half compared to similar work for our last commercial airliner, and it has established a model for all operations within the company. At the same time, the new approach has implications for the skills and attributes we seek from our current and future employees. In addition to specialized skills, we now expect employees to communicate well both in writing and orally, possess well-developed interpersonal skills, be aggressive listeners, and have a general understanding of a broad array of disciplines—or, at the very least, be quick learners.

Hiring and Developing Employees Who Can Adapt to Rapidly Changing Technology

Within a high-tech environment like The Boeing Company, technology tends to change faster now than in past decades. Employees must have core competencies, problem solving skills, and higher-level thinking skills to learn how to adjust to new technologies. Employees must be prepared intellectually and emotionally to deal with the fact that they may not have the same work assignment two years after they enter the job, or it probably will be broader in scope.

A good example of changing technology affecting every level of the company is the computer. Virtually every engineer must be knowledgeable of computer-aided design, since every new commercial airplane model is designed primarily by computer; the factory worker must operate and maintain numerically controlled machines; and secretaries must be able to operate some type of computer. Less than 10 years ago, the computer was not nearly as pervasive at Boeing as it is today.

Developing Managers as Coaches and Leaders

The autocratic management style advocated by theorist Frederick Taylor and others, which forced employees into narrow, inflexible jobs dictated by managers, has become increasingly counterproductive and outdated. With the impact of technology and the long overdue Theory Y management style, managers within new industrial cultures have different challenges. Boeing Company managers now bring employees together as teams, gleaning perspectives and knowledge from each employee and enhancing operations. Managers must be aggressive listeners, providing leadership to ensure that team and company goals are realized, and identifying attributes of employees that can empower employees as well as the team.

Operating Within a CQI Environment

The "one best way" environment of the scientific management era has been turned on its head within companies like Boeing. The focus now is on the continuous quality improvement (CQI) perspective that products, services, and processes can always be improved. If we listen to our customers, who want continuously higher quality at less cost, we must always improve. This simple, yet revolutionary philosophy emphasizes improving processes by reducing variation. Managers who concentrate on process move away from identifying peoples' errors to correcting process errors, thereby creating a non-intimidating environment for employees. Additionally, employees are provided with simple tools—statistical methodologies—to correct their own work processes, which in turn empowers and encourages them to do their best work.

These new approaches are beginning to have a significant, positive impact on the entire culture of the company. They also have serious implications for the desired skills and attributes of graduates who will enter companies like Boeing. For these reasons, we want to change the company's role in working with schools and colleges from being just a good corporate citizen to being actively involved in educational processes.

External Activities in which the Boeing Company is Involved

Beyond the previously stated approaches, society has an important challenge: correcting the ills of the nation's education system, particularly within the K-12 arena. Because of concerns with the educational system, The Boeing Company initiated a variety of programs involving schools and colleges, of which there are too many to list here. Over a nine year period, improving education has been the company's number one external priority. Boeing's CEO and chairman, Frank Shrontz, is personally at the forefront of many of these efforts. He said, "There are no quick fixes for the problems that affect our schools. The challenge is simply too big for any one sector of society to tackle alone. Educators cannot do it by themselves; neither can parents and students; nor businesses; nor even the combined resources of our local, state, and federal governments. The solution is partnerships that bring together individual citizens and groups from the public and private sectors."

One program that deals with educational issues through the partnership approach is the Tech Prep Applied Academics program, which was launched by The Boeing Company three years ago. Applied academics classes provide an alternative to students in high school who are focusing on something other than a college preparatory program. Rigorous, competency-based, hands-on, applied academics courses in physics, math, communications, biology, and chemistry prepare students for the manufacturing workforce. Students who take these courses usually do not intend to complete a bachelor's degree. Many will instead seek the associate degree offered at community colleges, where graduates who know how to apply these concepts are valued. This is what we regard as the Tech Prep connection. Through the Tech Prep model, students can take applied academics courses along with vocational-technical classes in their junior and senior years in high school and receive credit toward the completion of their associate degree, without needing additional terms for remedial work or fundamental skills. The Boeing Company is convinced that Tech Prep's integrated vocational and academic studies program is the most comprehensive way to prepare work-ready employees.

Thus far, Boeing has been involved in two phases of Tech Prep. In the initial phase, Boeing helped to build the applied academic foundation in the secondary-school system. During the second phase, we helped to promote the development of a statewide Tech Prep Manufacturing

Technology Degree program that was recently approved by the State Board for Community and Technical Colleges, and we continue to provide a work-based, student internship program related to manufacturing technology.

Phase 1—Building the Foundation (1990 to 1993)

First, the company provided over $3 million in funds to various high schools and local community colleges in Washington to establish applied academic programs and develop articulation agreements. Specifically, these funds were used as follows:

- Seed grants were given to 60 high schools throughout the state of Washington to implement applied academic programs in principles of technology (applied physics), applied mathematics, and applied communications.
- Articulation grants were awarded to community colleges for developing Tech Prep curricula in partnership with high schools that would allow high school juniors and seniors to take courses for credit toward an associate of arts degree.
- Boeing developed a summer high school teacher internship program that gives applied academics teachers experience in a manufacturing workplace environment that can be taken back to the classroom.

Phase 2—Developing a Manufacturing Technology Degree Program (1993 to Present)

In December 1992, Boeing and representatives from other industries, as well as labor, education, and state government formed an ad hoc committee to promote and support the development of a manufacturing education program for Washington state's existing and future workforce. This group is assisting community and technical colleges develop a manufacturing technology degree program that will teach students the broad, basic skills required to function effectively in today's increasingly complex and competitive manufacturing organizations.

The group's activities include:

- Identifying basic manufacturing entry-level skills; Soliciting involvement of other manufacturing firms in the state;
- Advising secondary schools, and community and technical colleges on a core curriculum that responds to industry's needs;
- Determining methods of measuring students' attainment of competencies; and
- Developing a recommended process by which industry can become involved effectively in Tech Prep.

The manufacturing technology program is designed to begin to develop broad basic manufacturing skills in high school—skills that are applicable to manufacturing and other fields as well. This should allow flexibility in career choices as the students expand their knowledge and begin focusing on their areas of interest. We want to keep the beginning course of study broad and basic, particularly at the high school level, so that a student does not have to choose a narrow career pathway before he/she has the time and opportunity to assess all possibilities. Thus, the applied academic courses and the manufacturing lab training are designed to provide the student with basic skills applicable and transferable to many areas of the real world of work.

In February 1993, The Boeing Company approved a summer internship program for students enrolled in the manufacturing technology program. This program provides students with three progressive summer sessions, beginning after 11 grade, in which they are introduced to career opportunities in manufacturing, taught basic factory skills, and advised on selecting specialty fields within manufacturing. The sessions are being coordinated with the high schools and colleges to ensure that the instruction complements the students' academic courses. The intern program began in the summer of 1993 with 25 students, and it is expected to reach nearly 300 students by 1997. During the summer of 1994, 100 students will be enrolled in internships. Concurrent with the student intern program, the company will continue the teacher internship program for secondary and two-year colleges that was started during Phase 1. Boeing's investment in the internship programs during the next five years will exceed $3.4 million.

A number of essential things are happening as a result of our efforts:

- *Close communication is developing between education and the private sector.* Programs the education community develop must reflect the kinds of knowledge, skills, and attitudes that employers expect. Employers hire graduates more readily if they have had a hand in shaping what is taught.
- *There is wide involvement of all players.* We are pleased to see high school teachers, two- and four-year college instructors, state vocational staff, union representatives, and private trade schools sitting down together to design these programs.
- *Academic and vocational faculty discover their mutual needs and concerns.* Each department has much to learn from the other and each will find students responding positively as subject matter is reinforced across disciplines. Major walls still in existence need to be broken down!
- *Equivalent credit is being awarded for equivalent outcomes.* I served on a special state legislative task force that recommended certain vocational coursework, approved by local districts, be accepted as the academic equivalent to core requirements for entry into the state's university system. The Higher Education Coordinating Board of Washington reviewed and approved this recommendation. As a result, it is expected that students will now enroll more freely in many of the high school vocational courses, knowing that it will not cause the doors to a baccalaureate degree to slam shut.
- *New coursework is being developed, not old ones warmed over.* Tech Prep requires instructors to re-examine totally the content of what they teach. It may require replacing old content with new, even adding new courses. It will require community and technical colleges to review seriously what is taught in the high schools so that students' precious time is not spent going over ground they have already covered. Truly competency-based approaches must be developed. If students are sent to a community college with a portfolio of skills already mastered, it won't be necessary to make those students take a test to prove what they already know. Community colleges must also review what and how they teach!

Students benefit from work-based experiences coupled with a strong applied academic curriculum. Our student internship pilot program in the summer of 1993 demonstrated clearly that a focused on-the-job experience can open new and relevant worlds to students. One student's comment expressed the feelings of many, "I learned more math during my four-week internship than in four years in school."

If Tech Prep is to have a long-range and pervasive impact on schools, colleges, and industry, considerable work must be done to ensure that business and industry will be full partners in the process. The Tech Prep conferences I have attended throughout the nation over the past two years demonstrate that industry basically is unaware of the Tech Prep movement, despite considerable enthusiasm within the educational community. Tech Prep is too important to be the exclusive purview of educators. Of all the recent educational reform efforts, Tech Prep has the greatest chance of becoming a truly collaborative partnership among educators, labor, government, and business and industry.

The Boeing Tech Prep effort provides a model, showing that true collaboration can work, and all participants can benefit. While our process is continually evolving, we believe we have made a good beginning, and we are convinced that we cannot rely on the same old approaches. We are focusing on real partnerships, real collaboration.

Tech Prep's time has come. The Boeing Company is glad to be in the position that it can help provide Tech Prep with some well-deserved visibility.

Carver C. Gayton is corporate director of College and University Relations at The Boeing Company.

Full-Scale Implementation: The Interactive "Whole Story"

Susan B. Millar

What is full-scale implementation? The National Science Foundation's (NSF) 1994 Project Impact conference organizers asked me to write a paper that describes, "key issues in moving from the development of pilot projects to full-scale implementation of major departures from traditional curricula or from traditional teaching approaches. Full-scale implementation includes, but is not limited to, adaptation/adoption of materials and approaches at other institutions, as well as in other disciplines or multiple sections of courses at the principal investigator's institution."

Pursuing this question, I asked project developers, "What is full-scale implementation? What are the key steps involved in getting there?" Most of them suggested key steps but did not want to suggest that, if you just complete some sequence of steps, voila, you have full-scale implementation. While there is value in delineating a sequential set of steps, the value is substantially lessened unless you get "the whole story." It's similar to knowing the basic plot of a movie but seeing only the last 15 minutes—you miss all the important moments and details in the rest of the story.

While we may need to learn the whole story, there is much to focusing on the end—how best to use publishable materials to disseminate the results of education reform projects. I realized that to limit the exploration of dissemination to a discussion of how best to utilize publications is to lose the capacity to articulate what many developers believe is the key to their success. This key is that, yes, without products and publications ("deliverables") you are unlikely to achieve full-scale implementation, but if you want to know how to achieve full scale, you need to focus on the *interactions* that take place during conversations and demonstrations. It is by bringing into focus the interactive situations in which these materials become real for others that we are able to understand how these materials actually come to be adopted/adapted widely. Without these conversations, the materials have limited value. Moreover, from such interactions education reformers can receive feedback and understand how they can help others grasp the essential features of their materials and approaches.

Developers who focus on the importance of interactive conversations/demonstrations are people who apply lessons learned in their reformed classrooms to the situations they encounter in professional meetings. Many of these developers spent years assuming that the more carefully organized and clearly presented their lectures, the easier it would be for students to acquire the purveyed knowledge. They eventually realized that excellent knowledge delivery in no way ensures that students understand and can effectively use knowledge. Abandoning their content-focused/delivery-based teaching approaches, they began developing student-focused/active-learning-based environments.

In the same fashion, these developers realized that creating and publishing a new textbook or piece of educational software and 'using standard traditional marketing do not ensure effective use of these materials. Principal investigators have opportunities to observe and compare the circumstances that do and do not move their faculty colleagues to adopt new approaches. Greg Miller captured the essence of what many other PIs said.

> I think telling and communicating the story about what you do and what the students do and how infrastructure plays into it is most effective. . . . Usually I'll start off talking about the ECSEL project and its goals and overall activities. . . . Then I move to my computer and demonstrate some of our directed information environments or

> some of our animations. That's often when people see a new term in the equation that puts some of the other things I've been talking about into real life and also makes them go, "Yes! I think that I could do some interesting things if I had that. . . ."
>
> For many people, learning doesn't happen when we show them just a couple of things. It happens when we give an indication that we've done the whole darn class this way—that you can scale it up. Unless you're able to show large-scale implementation, people will just think of it as a novelty. But when you show them that you've really institutionalized these classes, so that the same students who would normally take them are enrolling, and you aren't using an unusually high level of instructional resources, people can no longer think of it as a novelty. They get the idea that you can actually change the way you do things.

Positive reactions, such as those expressed by education reformer Greg Miller, point to important differences in basic assumptions used to make sense of education reform activity. To wit, the ideas that full-scale implementation can be understood as a definitive set of steps leading to a planned outcome and that the dissemination phase can be optimized by focusing on how best to use publishable materials are consistent with more linear, objectivist assumptions. The ideas that full-scale implementation entails "the whole story" and that efforts to isolate and understand a particular phase of dissemination should not focus on products/publications but on the interactions that take place during conversations and demonstrations are consistent with more nonlinear, interactionist assumptions.

To convey what it means for nonlinear, interactionist assumptions to inform one's approach to a project, I will now distill knowledge gained from a score of interviews and conversations into a schema that shows how moving to full-scale implementation entails a reform project's "whole story." Note that success in each phase turns upon complex interpersonal communications. It is these interactions that lead to the adaptation/adoption of materials and approaches at other institutions, as well as in other disciplines or multiple sections of courses at a PIs institution.

Phase 1. Articulate the need. Help colleagues and administrators understand that there is a gap between (1) standards and expectations for student learning held by faculty and/or students and/or society at large and (2) actual student learning experiences. For example, Jim Fasching found that his students could not answer in January the same questions they answered correctly in the previous December. More to the point, he found that telling others about this finding helped them understand that there is a gap between faculty expectations for, and the reality of, student learning. Once aware of this gap, they understood the need for reform.

Phase 2. Develop promising reform ideas and reform-ready colleagues. (1) Benchmark an existing "best practice" by reviewing the research on learning, attending conferences, and establishing informal networks of colleagues in one's own, and related, field(s). In the process, take note of people, in other departments and at other institutions, as you may wish to involve them as beta site testers. (2) Simultaneously seek reform-ready colleagues and brainstorm for ideas. Try to include high-status members of your own and other departments, graduate and undergraduate students, and people from both genders and diverse ethnicities. Stay clear of the, in Rob Cole's (The Evergreen State College) phrase, "reform vampires"—people who draw their sustenance from resisting people. (3) Move back and forth between Phase 1 and 2: as those in your emerging reform team develop their own ideas, their understanding of the need for change deepens.

Phase 3. Get a plan. Produce the proposals that will provide the requisite external and internal financial, administrative, and moral support. Use the "public accountability factor" to your advantage by helping your colleagues, chair, dean, and provost understand that the best way to deal with external demands for accountability is to stay ahead of the problem—on your own terms. Mort Brown advised approaching administrators with the following agenda: show the problem, show the solution and make clear that your unit will make a sacrifice, and demand resources. He cautioned that the moment you demand resources, deans demand evaluation data. Critically assess your institution's reform readiness. Your institution is ready only if you can enlist both a group of co-reformers who share your vision and a couple of key leaders/administrators who not only understand and care about the need you have identified but also have the power to help you. Included among these leaders should be at least one person from your institution and, optimally, people from other institutions who can bring pressure to bear on your department and college. (The coalition structure is useful insofar as it automatically connects you with leaders at other institutions.) If you encounter major resistance in your own department, seek support for a pilot project that may be used at some institution, leaving it to your colleagues to decide at a later time if they would like to adopt your approach. If you are at a research institution, involve graduate students as much as possible. During this phase you should also work with an evaluator who can help clarify research questions, plan how to acquire baseline data, and design your reform so that evaluation data are optimally useful. Meanwhile, keep benchmarking others' best-case practices.

Phase 4. Engage in initial implementation. Work with your reform colleagues to develop new materials, develop your new teaching methods, and so forth. Joe Lagowski, University of Texas, stressed the importance of developing examinations and assessments that "put a measure on" the new kinds of knowledge and skills that your reform seeks to help students develop. He emphasized that, to achieve full-scale implementation, colleagues who remain outside the reform effort must come to understand and accept these new assessments. Often this initial implementation phase involves interactions with a range of people—such as department chairs, registrars, student advisors, computer technicians, and space management personnel—and entails finding ways to simplify frustratingly complex implementation processes. Learn about and become facile in the politics of organizational change. Priscilla Laws of Dickinson College advised holding workshops on technique, philosophy, and the politics of change. Continue benchmarking.

Phase 5. Implement and evaluate the reform on a pilot basis. During the pilot stage, arrange for your evaluator to provide real-time formative feedback on student learning experiences, and/or use informal classroom assessment processes. Along these lines, Mort Brown advised, "Don't employ researchers who want to do evaluations in order to satisfy their own scientific criteria. You want to get the evaluation work out into someone else's hands, but make sure the evaluators understand your mission." Meet frequently with your co-reformers—including any graduate and undergraduate teaching assistants—to describe and reflect on your experiences and make midcourse corrections. Continue benchmarking.

Phase 6. Revise and beta test the reform. Engage interested colleagues to work with you as beta site testers. In selecting beta sites, be aware of the "prophet in his/her own land" syndrome: you are likely to have more trouble convincing your own colleagues than people in other disciplines at your institution or in your discipline elsewhere in the country. A second reason to conduct beta tests elsewhere is to assess whether your reform is robust in different environments and to learn how to adapt it to diverse environments without sacrificing essential features. Continue to obtain formative evaluations, meet frequently with your local and test site reform colleagues, and benchmark others' best-case practices.

Phase 7. Locate and work with a publisher. Assess whether you are producing materials that others may want copies of and begin looking for a publisher. Publishers may include the full range of commercial print establishments; organizations specializing in electronic, video, and audio media; and not-for-profit organizations such as your professional society or a campus education research center, or even your own reform team. Evaluate potential publishers in terms of their willingness and ability to work collaboratively with you. Look for publishers with such characteristics as:

- The capacity to build flexibility into your materials and approach so that users can modify them to suit their local needs.
- The ability to arrange situations that give you the best opportunities to interact with potential users with the least expenditure of your time. For example, your publisher might develop two or more workshop formats: a 1/2-day format for interested others who are still "scanning the options" and a 3-day format for people who are sold on your approach and want to learn how to implement it.
- The capacity to engage others at a sophisticated level. The publisher assumes that your new approach will attract only a portion of the potential users and that these users might be alienated by broad spectrum advertisements and missionary zeal. He/she ascertains what kind of person your reform is likely to attract and approaches these people with materials carefully designed to interest them. For example, Art Ellis (acting as his own publisher) is always ready to pull from his pocket little strips of "memory metal" which he uses to demonstrate how solid materials can provide superb ways to illustrate chemical principles. He has found that a little sample of metal acts as a hook that helps people make surprisingly sophisticated connections between everyday experiences and scientific abstractions. Another example is the low-budget video.
- Appropriate attitudes toward on-line electronic media. Your publisher should view on-line electronic media not as "the answer" but as a new kind of space in which interactive conversations/demonstrations can occur. In this regard, several developers emphasized that the availability of the World Wide Web does not, by itself, motivate others to use them and that students respond to these pages as yet another passive text. (While locating and working with your publisher, continue with iterations of Phase 6.)

Phase 8. Hand-off to the Publisher. Turn your materials and process over to the publisher as soon as you can bear to let them go.

Each of these phases depends on interaction. The phases themselves interact and double back on each other. Taken together, they compose a "whole story." But they do not compose *the* whole story. Each local reform story is played out within the larger structure of higher education, a structure which no single reform project team, or single institution, or all the publishers together can change. Attuned to the opportunities and constraints of this encompassing structure, many developers see the need for systemic change in how institutions of higher education promote educational reform. In particular, they find that their efforts to achieve full-scale implementation are seriously hampered because faculty lack opportunities to function on a sustained basis in change-agent roles. As Charles Patton of Oregon State University explains, "We need to address the issue of supporting people whose entire job, entire project, is taking somebody else's material, and somebody else's pedagogy, and moving it to other contexts. It was hoped that publishers would do this, and they have to a certain extent. But still the person who stands up there is Tom Dick of Oregon State University, or Greg Foley of Sam Houston State University, or me. There are only so many bodies and money is an issue. Consortiums work well because you have a lot more bodies and you can share the training work. But it's still not self-sustaining."

Phase 9. Work for change on the national level. Charles Patton's analysis suggests an additional phase in which PIs must engage with each other in order to achieve full-scale implementation—work for change on the national level. To move beyond a local and short-lived approach to full-scale implementation, PIs and others must work together to modify the opportunity structure within all of higher education. If we work collectively, we may be able to develop an infrastructure that allows each project team to teach others across the nation and allows teams to learn about and implement what other education reformers have learned. In this regard, it is very encouraging that NSF provides dissemination funds to projects that show evidence that their products and approaches are of interest to the academic community. These funds can be used for workshops, training workshop leaders, and providing loanable equipment and field test sites that agree to provide feedback. Finally, the success of this ninth, as well as all other phases, depends on making the most of the interactive conversations/demonstrations in which the value of your work becomes real for others.

Susan B. Millar is a cultural anthropologist and the Director of the University of Wisconsin—Madison's Learning through Evaluation, Assessment and Dissemination (LEAD) Services Center. Prior to assuming this position, she was a Research Associate at the Penn State Center for the Study of Higher Education, where she provided external evaluation for the NSF's Engineering Education Coalition, Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL) and completed a calculus reform assessment and dissemination project funded by the NSF's Division of Research, Evaluation and Dissemination.

Simulation and Modeling in Precollege Science Education

Wallace Feurzeig

Computer modeling of dynamic processes adds a new dimension to scientific and mathematical inquiry, complementing the classical paradigms of experiment and theory. A computer model is the concrete embodiment of a theory and a new kind of laboratory for exploration and experiment. Computer modeling can be a source of creative insights into the structure and behavior of complex phenomena that were previously inaccessible. It has made possible the solution of problems previously thought unsolvable and provides a bridge between theory and experiment, each contributing to the guidance the other in a new synergy that extends and enhances scientific inquiry.

Real-time interactive models with richly animated graphics displays, the same kinds of tools being used with great benefit in science research, can be made accessible to students. The models and modeling tools students work with are typically a great deal simpler than those used by scientists, but the fundamental character of the modeling activity is the same. The current school science course focuses on teaching about science; instead, students should be doing science. The introduction of modeling into schools provides a compelling new paradigm for making this innovation accessible to all students.

Computer modeling is valuable for students for very much the same reasons that it is for researchers. It enables students to observe and study complex processes and to see phenomena that are not accessible to direct observation, thereby enhancing students' comprehension of underlying mechanisms. Computer modeling can provide insight into the inner workings of a process or phenomenon, not just what happens, but why. It enables students to make and test predictions in situations where experimentation may be impractical or infeasible and gain information about a process that cannot be easily obtained otherwise, e.g., by slowing down or speeding up time or by presenting multiwindow views of different representations.

Modeling can dramatically enliven science education. A curriculum centered on modeling activities can foster the development of the notions and art of scientific inquiry in all students. Modeling microworlds can incorporate powerful graphic interfaces to enable easy interaction without the need for a deep understanding of computers. A computer modeling approach to teaching science has the potential for motivating the interest of significantly greater numbers of students, not just the small fraction who are already turned on to science and mathematics. Visual simulations and models can greatly aid students in understanding the complex dynamic behavior of systems composed of interacting subsystems, for example in studying reaction-diffusion equations in chemical interactions or the dynamics of competition, predation, and adaptation in multispecies population ecology models.

Science, mathematics, and technology will become increasingly important in people's lives and work in the 21st century. In order for students to acquire the knowledge, skills, and habits of mind required for enjoyable and productive activity in an increasingly demanding workplace, curriculum and instruction must become project-centered. Students must be engaged in projects that foster active, intensive experiences. Concepts that cut across traditional disciplines must be combined in explicit ways so that students can observe and work with the connections that arise in math and science. More time must be allowed for extended, in-depth project work. Science and math, instead of being isolated subjects, must become an integral part of other subjects through multidisciplinary, project-based curricular activities centered on modeling.

Modeling projects can forge changes in students' experience of mathematics and other subjects, with dramatic learning benefits. The experience of school math has given generations of students the view that, as well as being both difficult and dull, mathematics is far removed from anything genuinely real or interesting. Appropriate work in exploring, designing, and implementing mathematical models can profoundly change that perception. Modeling fosters an experimental approach toward solving problems. Modeling ideas and experiences can be structured to provide a natural foundation for teaching the art of logical thinking. The entire content of elementary and secondary mathematics can be developed in terms of modeling in a new kind of presentation that asserts a central role for technology in supporting serious educational purposes while showing that mathematics can be fun.

A rich variety of tasks that are interesting to students readily lend themselves to modeling investigations. These can be drawn from language, art, music, and other domains in areas and tasks of personal interest to students. They include such things as building semantic grammars for generating and producing poetry, jokes, or songs; making and breaking "secret codes" defined by functional composition; designing and constructing complex geometric tiling and weaving patterns; modeling architectural and engineering structures and mechanisms with program-controlled drawing and milling devices; developing problem-solving strategies for sensor robots; and an enormous body of other constructive problem-solving projects in virtually all subject areas and levels of complexity. Modeling provides a natural opportunity for student collaboration through work on team projects such as assessing and reducing the loss of oxygen in the ecosphere; building a city for the future; going on a voyage of discovery to a new world; developing a dynamic electronic atlas showing patterns of change in U.S. geography, weather, and demography; and learning to navigate a space vehicle on realistic space explorations.

Aside from art and shop work, school activities are seldom directed at raising students' interest outside of school, making students feel the activities are really theirs, or allowing students to design and build projects themselves. Modeling activities are an exception. At the same time, these activities are natural sources for rich learning experiences. They engage students in reflective problem-posing and problem-solving work involving strategic planning, precise formal thinking, and constructive design. In contexts such as these, students do not feel burdened by the need to acquire mathematical or extracurricular knowledge to accomplish their purpose.

Computational facilities once limited to the science research community are becoming increasingly available for use in precollege science education. These facilities include networking resources, parallel modeling languages, data visualization tools, computer-based laboratory probes, and virtual reality environments. However, there is a significant lag between the new technological capabilities and the ability to implement them effectively.

Many practical issues arise in bringing modeling into the K–12 science curriculum. Recent workshops and symposia on computer modeling and simulation in science education, under a project supported by NSF, explored ways to develop a coherent framework for guiding research and development that can advance the classroom application of appropriate technology. Participants included curriculum and software developers, teachers, scientists and mathematicians, educational researchers, and experts in computer simulation and modeling technology. Their presentations demonstrated an abundance of modeling ideas and applications and showed the richness and diversity of educational modeling applications made possible by current technology.

The discussions centered on several technological and pedagogical issues that were viewed as key for guiding effective educational use of modeling. These issues include the relationship between the modeling methods and tools used in science research and those used for modeling in science education; the relationship between computer-based modeling activities and real-world observation and laboratory experimentation; the relationship between learning to use models and learning to design and build models, and the relationship between computer visualization of a model's output behavior and computer visualization of a model's structure and component processes.

Participants have developed in-depth case studies of examples of some of the best educational modeling work to provide a concrete source of reference materials for illustrating their views on the issues. The studies will be published in a special issue of the journal *Interactive Learning Environments*. A discussion session will draw on these case studies to focus on ways to use modeling technology effectively to benefit pedagogy.

Wallace Feurzieg is affiliated with Bolt, Beranek, and Newman.